

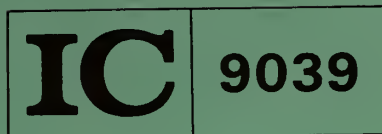
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Chemically Enhanced Drilling

An Annotated Tabulation of Published Results

By Pamela J. Watson and William H. Engelmann



UNITED STATES DEPARTMENT OF THE INTERIOR



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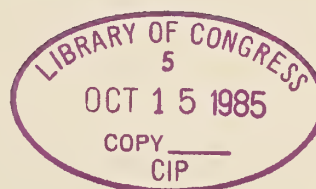
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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.



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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

eq/L	equivalent per liter	mol	mole
g/L	gram per liter	mol/L	mole per liter
in	inch	<u>N</u>	normality
lb/ton	pound per ton	pct	percent
mg/g	milligram per gram	wt pct	weight percent
mg/L	milligram per liter		

CHEMICALLY ENHANCED DRILLING

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By Pamela J. Watson¹ and William H. Engelmann²

ABSTRACT

This report presents a Bureau of Mines literature survey that provides a data base useful for current and future studies in the area of chemically enhanced drilling and cutting. Publications describing laboratory testing and field studies of drilling and cutting with chemical additives are reviewed. Significant results are summarized and tabulated by rock or material type and also by chemical additive, with extensive references. Selected studies related to fluid-enhanced processing or material testing are summarized in the appendixes.

¹Mining engineer.

²Research chemist.

Twin Cities Research Center, Bureau of Mines, Minneapolis, MN.

INTRODUCTION

The goals of the Bureau of Mines include that of increasing productivity in mining systems. Enhanced rates of fragmentation or excavation result from faster penetration rates of rock drills for blastholes, or other advanced drilling practices associated with the total mining process. Since large drilling machines are capital intensive and smaller rock drills are labor intensive, the enhancement of drilling rates has been a productivity goal for many decades as a response to these economic pressures. Flushing water had been used with many original designs of rock drills. However, it is not known when chemical additives were first used in these flushing fluids, since much of the early work in this area is known only through hearsay and was not published. Secondhand reports of this use of chemical additives began to appear in the literature, most notably in the 1920's.

In over 60 years of drilling technology, nearly 100 different additives have been reported in the literature, with many descriptions of their effects. However, results given for drillability on the same rock type, with the same additive, at the same concentration, vary widely from one researcher to another, depending upon experimental approach and conditions. Accordingly, the Bureau has undertaken this literature review in order to bring together all the results, albeit with their variances, and to present a concise, easily consulted data base as a guide for mining companies and drilling technologists, as well as a lead-in to chemically enhanced drilling and cutting research that is being pursued by the Bureau and others. Researchers in the United States and elsewhere

made progress in understanding the effects of chemical additives in the period 1960-75, but despite the importance of these studies, only limited advances have been made in the last decade. It is now generally accepted that there is no one generic mechanism that yields understanding of the accumulation of all phenomena or effects that are observed.

This review reports from the literature which chemicals have been found to enhance drilling and cutting of rocks and materials, summarizes these rock-fluid interactions, and tabulates the degrees and varieties of success for these interactions. In addition, many of the same rock-fluid combinations useful in enhancing drilling and cutting have also been used in studying (1) processing methods, such as comminution and grinding, flotation, or fragmentation, (2) surface effects, including adsorption, friction and wear, Rebinder effects, or zeta potential modifications to rock hardness, and (3) mechanical property alteration, including hardness, fracture and crack formation and propagation, and strength of materials. There are also numerous other rock-fluid combinations not yet reported in drilling practice that have been used in these related areas. Appendix A lists rock-fluid combinations used in processing studies, along with a corresponding bibliography; appendix B lists rock-fluid combinations used in surface effects studies, with bibliography; and appendix C lists rock-fluid combinations used in studies of the mechanical properties of materials, with bibliography. In addition, a general bibliography on drilling is listed in appendix D.

REVIEW OF LITERATURE

A great number of different rock types have been tested in both the field and the laboratory to determine the effects of various fluid additives on drilling performance. The following sections and tables summarize the reported relative success of the numerous chemical

additives and rock or material combinations in enhancing the drilling process.

ROCKS OR MATERIALS

Many different rocks or materials have been field- or laboratory-tested using a

great variety of fluid additives. The rocks and materials are--

Amygdaloidal basalt
 Anhydrite (including gypsum and sulfate rocks)
 Argillaceous rocks (including argillites, clays, schists, and shales)
 Calcium fluoride crystals
 Chert
 Coal (New South Wales coal measure and Novo Khazinskii and Arlanskii coal deposits of the Arlansk coal region)
 Diabase
 Diorite
 Dolomite
 Garnetite
 Granite (many varieties tested; see references for specific type)
 Granodiorite
 Greenstone
 Gritstone
 Hematite (including taconite)
 Igneous rocks (see also basalt, diabase, diorite, granite, granodiorite, and rhyolite and porphyry)
 Ironstone (including jaspilite)
 Limestone (including carbonate rock)
 Lithium fluoride crystals
 Magnesite
 Magnesium oxide crystals
 Marble
 Martite
 Microcline
 Pyrite
 Quartz
 Quartzite
 Rhyolite and porphyry
 Riebeckites
 Sandstone
 Serpentine
 Siderite
 Tuff

Table 1 summarizes the results of the drilling tests reported in the literature. This table breaks down the results first by rock type, then lists the chemical additives tested, the concentrations (footnoting the optimum concentration if available), the property of the rock or the drilling, the corresponding effect, and the specific reference. All effects were compared to those from drilling with water alone, unless otherwise noted.

CHEMICAL ADDITIVES

The literature has reported a great variety of chemical additives used in field or laboratory tests in attempts to enhance drilling in a given rock or material. These additives with their chemical formulas and/or general descriptions, if known, are--

Aerosol (no specific formula or description given)
 Aerosol C-61 (cationic surfactant)
 Aerosol OT (anionic surfactant)
 Aluminum chloride (AlCl_3)
 Ammonium nitrate (NH_4NO_3)
 Anionic detergent
 B.P.S.B.4 (soluble oil)
 Calcium chloride (CaCl_2)
 Calcium hydroxide [$\text{Ca}(\text{OH})_2$]
 Compound "M" (no specific formula or description given)
 Conco XAC (surfactant)
 Conco XAM (surfactant)
 Consoft C (surfactant)
 Consoft CP-50 (surfactant)
 Cutall oil (no specific formula or description given)
 Dimethylformamide (DMF) [$(\text{CH}_3)_2\text{NHC}\text{O}$]
 Dimethylsulfoxide (DMSO) [$(\text{CH}_3)_2\text{SO}$]
 DMF in DMSO
 Disolvane 4411 (surfactant)
 Dodecylamino acetate ($\text{C}_{12}\text{H}_{25}\text{NH}_2\text{C}_3\text{H}_7\text{O}_2$)
 Dodecyltrimethyl ammonium bromide (DTAB) ($\text{C}_{15}\text{H}_{34}\text{NBr}$)
 Dromus B (soluble oil)
 Dromus B plus Esso 1 (combination of two soluble oils)
 Duomac T (surfactant)
 Ethyl alcohol ($\text{C}_2\text{H}_5\text{OH}$)
 Ethylene glycol ($\text{C}_2\text{H}_6\text{O}_2$)
 Ferric chloride (FeCl_3)
 Glycerine ($\text{C}_3\text{H}_8\text{O}_3$)
 Hetoxamine C-10 (surfactant)
 Hydrochloric acid (HCl)
 Intersoft 49 (surfactant)
 Kerosine
 Lime (CaO)
 Magnesium chloride (MgCl_2)
 Magnesium sulfate (MgSO_4)
 Marvansoft FBH (surfactant)
 Marvansoft FMA (surfactant)
 Mobil 1535 (soluble oil)

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type

Additive ¹	Concentrations tested, wt pct ²	Property	Effect ³	References ⁴
AMYGDALOIDAL BASALT ⁵				
Oleylammonium acetate.....	⁶ 0.01	Drilling costs.. Drilling rate...	Reduced..... Increased 20 to 50 pct.	} 4
Tergitol 7.....	⁶ .1	Drilling costs.. Drilling rate...	Reduced..... Increased 20 to 50 pct.	
Tergitol NPX.....	⁶ .1	Drilling costs.. Drilling rate...	Reduced..... Increased 20 to 50 pct.	} 4
ANHYDRITE				
Aluminum chloride ⁷	0.1 - 1.0	Bit wear..... Drilling speed..	Decreased 10 pct..... Increased 20 pct.....	} 18
Calcium chloride ⁷	.1 - 1.0	Bit wear..... Drilling speed..	Decreased 10 pct..... Increased 20 pct.....	
Calcium hydroxide.....	⁶ 0.06	Bit life..... Bit wear..... Drilling rate...	Increased..... Decreased..... Increased.....	} 18, 30
		Rock hardness... Rock strength...	Decreased..... Decreased 9 to 20 pct..	
Sodium carbonate ⁷	.1 - 1.0	Bit wear..... Drilling speed..	Decreased 10 pct..... Increased 20 pct.....	
Sodium chloride ⁷	.1 - 1.0	Bit wear..... Drilling speed..	Decreased 10 pct..... Increased 20 pct.....	
Sodium hydroxide.....	⁶ 0.05 - .1	Bit life..... Bit wear..... Drilling rate...	Increased..... Decreased..... Increased.....	} 18, 30
		Rock hardness... Rock strength...	Decreased..... Decreased 9 to 20 pct..	
Do. ⁷	.1 - .2	Amount drilled.. Drilling rate...	Increased..... ...do.....	
		Drilling speed..	...do.....	
ARGILLACEOUS ROCKS				
SHALES				
Aluminum chloride.....	0.1	Bit life..... Bit wear..... Drilling rate...	Increased..... Decreased..... Increased.....	} 30
		Rock hardness... Rock strength...	Decreased..... Decreased 9 to 20 pct..	
Do. ⁸⁻⁹	¹⁰ 0.0 - .05	Bit wear..... Drilling rate...	Reduced..... Increased 15 to 40 pct.	
Do. ⁸⁻⁹	.0075- .03	Drill thrust... Rock hardness...	Reduced..... ...do.....	
Dromus B ¹¹	¹² .91 ¹³ .13	Bit life..... Drilling rate...	Increased very markedly ...do.....	} 9
Do. ¹¹	¹² .67 ¹⁴ .17	Bit wear..... Drilling rate...	Reduced..... Increased.....	
		Drill vibration. Lifting action.. Pump pressures..	Eliminated..... Improved..... Reduced.....	} 10
Hydrochloric acid ⁸	.0 - .5	Bit wear..... Drilling rate...	Reduced..... Increased 15 to 40 pct.	
Magnesium chloride ⁸	.0 - .3	Bit wear..... Drilling rate...	Reduced..... Increased 15 to 40 pct.	
SMAD 1 ⁷	NA	NA.....	NE.....	
Sodium carbonate.....	.25	Bit life..... Bit wear..... Drilling rate...	Increased..... Decreased..... Increased.....	} 30
		Rock hardness... Rock strength...	Decreased..... Decreased 9 to 20 pct..	

See notes at end of table.

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type--Con.

Additive ¹	Concentrations tested, wt pct ²	Property	Effect ³	References ⁴
ARGILLACEOUS ROCKS--Continued				
SHALES--Continued				
Sodium carbonate ⁷	NA	Amount drilled.. Drilling rate... Drilling speed... Overall efficiency.	Slightly increased.... ...do..... ...do..... Increased.....	19
Do. ⁸	¹⁵ 0.0 - 0.5	Bit wear..... Drilling rate...	Decreased..... Increased 15 to 40 pct.	
Sodium carbonate, plus sodium hydroxide. ⁷	NA	Amount drilled.. Drilling rate... Drilling speed... Overall efficiency.	Slightly increased.... ...do..... ...do..... Increased.....	19
Sodium chloride ⁷	.25 1.0 - 2.0	Amount drilled.. Drilling rate... Drilling speed... Overall efficiency.	Slightly increased.... ...do..... ...do..... Increased.....	
Do. ⁸	16.0 - 3.5	Bit wear..... Drilling rate...	Reduced..... Increased 15 to 40 pct.	23
Sulfanol ⁷	.05 - .15	Bit energy..... Bit friction... Drilling rate... Rock strength...	Decreased..... ...do..... Increased..... Decreased.....	
Sulfate soap ⁷	NA	NA.....	NE.....	5
Thorium chloride ⁸	.0 - .03	Bit wear..... Drilling rate...	Reduced..... Increased 15 to 40 pct.	23
ARGILLITES AND SCHISTS				
Sodium carbonate.....	.1 - .25	Bit wear..... Drilling rate...	Decreased 10 to 35 pct. Increased 20 to 60 pct.	26
CLAY ROCKS				
Sodium chloride plus sodium carbonate.	.1 - .5	Bit life..... Bit wear..... Drilling rate... Rock hardness... Rock strength...	Increased..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..	30
SHALES, ARGILLITES AND SCHISTS, CLAY ROCKS				
Sodium chloride.....	.25 - .5	Bit life..... Bit wear..... Drilling rate... Rock hardness... Rock strength...	Increased..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Decreased..... Decreased 9 to 20 pct..	30 26, 30 26, 30 30 30
CALCIUM FLUORIDE CRYSTALS ⁸				
Aluminum chloride.....	NA	NP.....	NE.....	31
Dimethyl formamide (DMF)...	0 -100	} Rock hardness...	Reduced.....	31-32
Dimethyl sulfoxide (DMSO)...	0 -100			
DMF in DMSO.....	0 - 50			
n-alkanes.....	NA	Drilling rate...	Increased.....	31
Toluene.....	NA	NP.....	NE.....	31
CHERT ¹¹				
Dromus B.....	¹⁷ 0.91 ¹⁸ .13	Bit life..... Drilling rate... Rod grease.....	Increased very markedly ...do..... Not required.....	9

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type--Con.

Additive ¹	Concentrations tested, wt pct ²	Property	Effect ³	References ⁴
CHERT ¹¹ --Continued				
Dromus B plus Esso 1.....	5 - 7	Bit life..... Drilling rate... Rod grease.....	Increased very markedly ...do..... Not required.....	9
COAL				
Disolvane 4411 ¹⁹	NA	NP.....	NE.....	22
Dromus B ²⁰	1.0	Bit life..... Drilling rate... Rod grease.....	Increased markedly.... Increased..... Required.....	9
OP-10 ¹⁹	0.05 - .12	Bit life..... Bit wear..... Drilling rate...	Increased..... Decreased..... Increased.....	
SNS ¹⁹	NA	NP.....	NE.....	22
DIABASE ⁷				
Aluminum chloride.....	0.17 - 0.22	Drilling costs.. Drilling rate...	Decreased..... Significantly increased	19
Magnesium chloride.....	.75 - 1.5	Drilling costs.. Drilling rate...	Decreased..... Slightly increased....	
Magnesium sulfate.....	.25	Drilling costs.. Drilling rate...	Decreased..... Slightly increased....	19
Sodium carbonate.....	.75	Drilling costs.. Drilling rate...	Decreased..... Slightly increased....	
Sodium chloride.....	.4 - 1.0	Drilling costs.. Drilling rate...	Decreased..... Slightly increased....	19
DIORITE ⁷				
Aluminum chloride.....	0.2	} Drilling rate...	NE.....	19
Sodium carbonate.....	.5		...do.....	Increased.....
Sodium chloride.....	.2			
DOLOMITE				
Dromus B ¹¹	0.13 - 0.91	Bit life..... Drilling rate... Rod grease.....	Increased markedly.... ...do..... Not required.....	9
Do. ⁷	.67	Bit wear..... Drilling rate... Drill vibration. Lifting action.. Pump pressures..	Decreased..... Increased..... Eliminated..... Improved..... Reduced.....	
Ethyl alcohol.....	NA	Drilling rate...	Increased 70 pct.....	20
Hydrochloric acid.....	<1.0	Bit wear..... Drilling speed.. Rock hardness...	Decreased 10 pct..... Increased 20 pct..... Decreased 80 pct.....	18
Sodium hydroxide plus sodium carbonate.	.06 - .2	Amount drilled.. Bit wear..... Drilling rate... Drilling speed..	Increased..... Decreased 54 pct..... Increased..... Slightly increased....	
Sulfite cellulose lye.....	50	Bit wear..... Drilling speed.. Rock hardness...	Decreased 10 pct..... Increased 20 pct..... Decreased 80 pct.....	18
Sulfonaphthenic petroleum acids.	1 - 2	Bit wear..... Drilling speed.. Rock hardness...	Decreased 10 pct..... Increased 20 pct..... Decreased 80 pct.....	
GARNETITE ²¹				
Solvac.....	1.0	Bit life..... Drilling rate... Rod grease.....	Increased markedly.... Increased very markedly Not required.....	9

See notes at end of table.

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type--Con.

Additive ¹	Concentrations tested, wt pct ²	Property	Effect ³	References ⁴
GRANITE				
Aluminum chloride ⁸	0.05	Amount drilled..	Increased.....	19
		Drilling rate...	...do.....	
		Drilling speed..	...do.....	
Ammonium nitrate ⁷	.02	Amount drilled..	...do.....	19
		Bit corrosion...	Extreme.....	
		Drilling rate...	Increased.....	
		Drilling speed..	...do.....	
B.P.S.B.4 ²²	2.5	Bit life.....	Increased very markedly	9
Dromus B plus Esso 1 ¹¹	5 - 7	...do.....	...do.....	9
		Drilling rate...	...do.....	
Magnesium chloride ²³	.1	Amount drilled..	Increased.....	19
		Drilling rate...	...do.....	
		Drilling speed..	...do.....	
Mud: ⁸				
Bentonite clay.....	5.6	} Bit wear.....	Reduced.....	7
Sodium bicarbonate.....	.9			
Sodium chloride.....	13.4			
Tap water.....	80.05			
n-alcohols (methane to deconal).	NA	NP.....	NE.....	12, 32
Naphthenic acid soap	.25 - .5	Bit wear.....	Decreased 10 to 35 pct.	26
plus sodium carbonate.	.25	Drilling rate...	Increased 20 to 60 pct.	
Sodium carbonate ⁷	.25	Amount drilled..	Increased.....	19
		Drilling rate...	...do.....	
		Drilling speed..	...do.....	
Sodium chloride ⁷	.1 - .5	Amount drilled..	...do.....	19
		Drilling rate...	...do.....	
		Drilling speed..	...do.....	
Aerosol C-61 ⁸mol/L..	10 ⁻⁴ - 10 ⁻²	Bit life.....	Increased 4 to 5 times.	12, 14, 16, 18
		Bit wear.....	Decreased 4.8 times....	
		Drilling rate...	Increased.....	
Aerosol OT ⁸mol/L..	10 ⁻³ - 10 ⁻²	NP.....	NE.....	14
Aluminum chloride ⁸mol/L..	3 × 10 ⁻⁶	Bit wear.....	Minimized.....	1, 14
		Rock hardness...	Maximized.....	
Dodecyltrimethyl ammonium bromide (DTAB) ⁸mol/L..	10 ⁻⁴ - 10 ⁻³	Bit life.....	Increased.....	8, 12, 14-15, 17, 32
		Drilling costs..	Reduced.....	
		Drilling rate...	Increased 3 to 4 times.	
GRANODIORITE				
Aluminum chloride.....	0.01 - 0.05	Drilling rate...	Increased.....	6
		Rock hardness...	Minimized.....	
Magnesium chloride.....	.01 - .05	Drilling rate...	Increased.....	6
		Rock hardness...	Minimized.....	
Do. ^{7,23}	.9 - 1.5	Drilling rate...	Increased.....	19
Sodium carbonate.....	.01 - .1	...do.....	...do.....	6
		Rock hardness...	Minimized.....	
Sodium chloride ^{7,23}	1.0	Drilling rate...	Increased.....	19
Do.....	.1	...do.....	...do.....	6
		Rock hardness...	Minimized.....	
Sugar.....	.1 - 1.0	Drilling rate...	Increased.....	6
		Rock hardness...	Minimized.....	
Aluminum chloride.....N..	.005	} ...do.....	...do.....	3
Magnesium chloride.....N..	.05			
Sodium chloride.....N..	.05			

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type--Con.

Additive ¹	Concentrations tested, wt pct ²	Property	Effect ³	References ⁴
GREENSTONE				
Aerosol ²⁴	0.8	Drilling effectiveness.	Increased.....	11
Compound "M" ²⁴	.2			
Cutall oil ²⁴	20.0			
Kerosine ²⁴	Pure			
Mobil 1535 ²¹	4.0	Bit life.....	NE.....	9
		Drilling rate...		
Water ²⁴⁻²⁵	NAP	Drilling effectiveness.	Increased to maximum...	11
GRITSTONE				
Aluminum chloride ⁷⁻⁸	0.0 - 0.05	Bit wear.....	Reduced.....	23
		Drilling rate...	Increased 15 to 40 pct.	
Do. ⁷⁻⁸	.0075- .03	Drill thrust....	Reduced.....	24
		Rock hardness...	...do.....	
Hydrochloric acid ⁸⁻⁹	.0 - .5	NP.....	NE.....	23
Magnesium chloride ⁸⁻⁹	.0 - .3			
Sodium carbonate ⁸⁻⁹	.0 - .5			
Sodium chloride ⁸⁻⁹	.0 - 3.5			
Thorium chloride ⁸⁻⁹	.0 - .03			
HEMATITE				
Aluminum chloride.....	0.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
Ferric chloride.....	.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
Sodium chloride.....	0.1 - .25	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
Aerosol C-61 ^{8,26}mol/L..	10 ⁻⁴ - 10 ⁻²	Bit life.....	Increased 5-fold.....	13
		Bit wear.....	Decreased 4.8 times....	
IGNEOUS ROCKS ²⁷				
Aluminum chloride.....	0.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased.....	
		Drilling rate...	Increased.....	
		Rock hardness...	Decreased.....	
		Rock strength...	Decreased 9 to 20 pct..	
Sodium carbonate plus soap (unspecified).	.25 .25	Bit life.....	Increased.....	30
		Bit wear.....	Decreased.....	
		Drilling rate...	Increased.....	
		Rock hardness...	Decreased.....	
		Rock strength...	Decreased 9 to 20 pct..	
Sodium chloride.....	0.1 - .25	Bit life.....	Increased.....	30
		Bit wear.....	Decreased.....	
		Drilling rate...	Increased.....	
		Rock hardness...	Decreased.....	
		Rock strength...	Decreased 9 to 20 pct..	

See notes at end of table.

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type--Con.

Additive ¹	Concentrations tested, wt pct ²	Property	Effect ³	References ⁴		
IRONSTONE						
Aluminum chloride ⁷	0.1 - 0.15	Amount drilled.. Bit wear..... Drilling rate... Drilling speed..	Increased..... Decreased 26 pct..... Increased..... ...do.....	19		
Dromus B ¹¹	28.91 29.13	Bit life..... Bit wear..... Drilling rate... Drill vibration. Lifting action.. Pump pressures..	Increased very markedly Decreased..... Increased very markedly Eliminated..... Improved..... Reduced.....		9 9-10 9-10 9-10 9-10 9-10	
Do. ³⁰⁻³¹	NA	Bit life..... Drilling rate... Rod grease.....	Increased very markedly Increased markedly.... Not required.....		9	
Magnesium chloride ⁷	.3	Amount drilled.. Bit wear..... Drilling rate... Drilling speed..	Increased..... Decreased 26 pct..... Increased..... ...do.....			19
Sodium chloride ⁷	.25	Amount drilled.. Bit wear..... Drilling rate... Drilling speed..	...do..... Decreased 26 pct..... Increased..... ...do.....	19		
LIMESTONE						
Aluminum chloride ⁸⁻⁹	0.0 - 0.5	Bit wear..... Drilling rate...	Reduced..... Increased 9 pct.....		23	
Calcium chloride.....	1.0	Amount drilled.. Drilling rate... Drilling speed..	Increased..... ...do..... ...do.....			19
Calcium hydroxide.....	.05 - .07	Bit life..... Bit wear..... Drilling rate... Rock hardness... Rock strength...	...do..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..	30		
Hydrochloric acid ^{7,32}	1.0	Bit wear..... Drilling speed..	Decreased 10 pct..... Increased 10 to 70 pct.		18	
Do. ³²	.1 - .3	Amount drilled.. Drilling rate... Drilling speed..	Increased..... ...do..... ...do.....	19		
Do. ^{8-9,32}	.0 - .5	Bit wear..... Drilling rate...	Reduced..... Increased 9 pct.....		23	
Magnesium chloride.....	15.25 - 1.0	Amount drilled.. Drilling rate... Drilling speed..	Increased..... ...do..... ...do.....	19		
Do. ⁸⁻⁹	.0 - .3	Bit wear..... Drilling rate...	Reduced..... Increased 9 pct.....		23	
Magnesium sulfate.....	.75 - 1.0	Amount drilled.. Drilling rate... Drilling speed..	Increased..... ...do..... ...do.....	19		
Mud: ⁸		} Bit wear.....	Reduced.....		7	
Bentonite clay.....	5.6					
Sodium bicarbonate.....	.95					
Sodium chloride.....	13.4					
Tap water.....	80.05					
Oil soap.....	.1 - 1.0	Amount drilled.. Drilling rate... Drilling speed..	Increased..... ...do..... ...do.....	19		

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type--Con.

Additive ¹	Concentrations tested, wt pct ²	Property	Effect ³	References ⁴
LIMESTONE--Continued				
Sodium carbonate ⁷	0.25	Amount drilled..	Increased.....	19
		Bit life.....	...do.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	19, 26, 30
		Drilling speed..	Increased.....	19
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
Do. ⁷	0.1 - 1.0	Bit wear.....	Decreased 10 pct.....	} 18
		Drilling speed..	Decreased 10 to 20 pct.	
Do.....	.0 - .5	Amount drilled..	Increased.....	} 19
		Drilling rate...	...do.....	
		Drilling speed..	...do.....	
Do. ⁸⁻⁹	.0 - .5	Bit wear.....	Reduced.....	} 23
		Drilling rate...	Increased 9 pct.....	
Sodium chloride ⁷	.25	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
Do.....	.75	Amount drilled..	Increased.....	} 19
		Drilling rate...	...do.....	
		Drilling speed..	...do.....	
Do. ⁸⁻⁹	¹⁶ .0 - 3.5	Bit wear.....	Reduced.....	} 23
		Drilling rate...	Increased 9 pct.....	
Sodium hydroxide.....	.05	Bit life.....	Increased.....	} 30
		Bit wear.....	Decreased.....	
		Drilling rate...	Increased.....	
		Rock hardness...	Decreased.....	
		Rock strength...	Decreased 9 to 20 pct..	
Do.....	.1 - .2	Amount drilled..	Increased.....	} 19
		Drilling rate...	...do.....	
		Drilling speed..	...do.....	
Sodium hydroxide plus sodium carbonate (1:1).	.05 - .2	Amount drilled..	...do.....	} 19
		Drilling rate...	...do.....	
		Drilling speed..	...do.....	
Sodium phosphate ⁷	.1	Bit wear.....	Decreased 10 to 35 pct.	} 26
		Drilling rate...	Increased 20 to 60 pct.	
Sodium silicate ⁷	.025	Bit wear.....	Decreased 10 to 35 pct.	} 26
		Drilling rate...	Increased 20 to 60 pct.	
Sulfite cellulose lye ⁷	50	Bit wear.....	Decreased 10 pct.....	} 18
		Drilling speed..	Increased 10 to 70 pct.	
		Rock hardness...	Decreased 30 to 50 pct.	
Sulfonaphthenic petroleum acids. ⁷	1 - 2	Bit wear.....	Decreased 10 pct.....	} 18
		Drilling speed..	Increased 10 to 70 pct.	
		Rock hardness...	Decreased 30 to 50 pct.	
Thorium chloride ⁸⁻⁹	.0 - .03	Bit wear.....	Reduced.....	} 23
		Drilling rate...	Increased 9 pct.....	
LITHIUM FLUORIDE CRYSTALS ⁸⁻⁹				
DMF.....	NA NA NAP	} Bit life.....	Increased.....	13
Toluene.....				
Water ²⁵				
See notes at end of table.				

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type--Con.

Additive ¹	Concentrations tested, wt pct ²	Property	Effect ³	References ⁴
MAGNESITE				
Aluminum chloride.....	0.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
Ferric chloride.....	.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
Sodium chloride.....	0.1 - .25	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
MAGNESIUM OXIDE CRYSTALS ⁸				
Aluminum chloride.....	NA	Drilling rate...	Increased.....	32
DMF.....	0 -100	...do.....	...do.....	15, 32
DMSO.....	0 -100	...do.....	...do.....	32
DMF in DMSO.....	0 - 50	...do.....	Increased 20 times.....	8, 32
		Rock hardness...	Decreased.....	31
n-alkanes ³³	NA	Drilling rate...	Increased 8 times.....	20, 32
Toluene.....	Pure	...do.....	Increased.....	15, 32
Water.....	Nap	...do.....	NE.....	15
Sodium chloride.....N..	10 ⁻²	Bit life.....	Increased 5 times.....	13
		Drilling rate...	Increased.....	8
MARBLE ⁸				
Aluminum chloride.....	0.5 - 1.0	Drilling rate...	NE.....	2
Magnesium chloride.....	NA	...do.....	NE.....	29
Mud:				
Bentonite clay.....	5.6	} Bit wear.....	Reduced.....	7
Sodium bicarbonate.....	.95			
Sodium chloride.....	13.4			
Tap water.....	80.05			
Soap.....	.25 - .5	} Drilling rate...	NE.....	2
Sodium carbonate.....	.2 - 1.0			
Sodium hydroxide.....	.025 - .25			
Quat 316.....mol/L..	10 ⁻³ - 10 ⁻²			
MARTITE				
Aluminum chloride.....	0.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
Ferric chloride.....	.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
Sodium chloride.....	0.1 - .25	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type--Con.

Additive ¹	Concentrations tested, wt pct ²	Property	Effect ³	References ⁴
MICROCLINE				
Aluminum chloride ⁸	0.0001- 1.0	} NP.....	NE.....	29
Magnesium chloride ⁸	.0001- 1.0			
DTAB.....mol/L..	10 ⁻⁴ - 10 ⁻³	Drilling rate...	Increased.....	15, 29
PYRITE				
Aluminum chloride.....	0.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
Ferric chloride.....	.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
Sodium chloride.....	0.1 - .25	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
Do. ⁷⁻⁸	.1 - .5	Drilling speed..	Increased.....	19
QUARTZ				
Aluminum chloride ⁷	0.01 - 0.05	Drilling rate...	Increased.....	} 6
		Rock hardness...	Decreased.....	
Do.....	.02 - .1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
Do. ⁷	.7 - 1.0	Amount drilled..	Increased.....	} 19
		Bit wear.....	Decreased 34 pct.....	
		Drilling speed..	Increased.....	
B.P.S.B. ⁴²²	2.5	Bit life.....	Increased very markedly	9
Dodecylamino acetate ⁷	NA	Bit wear.....	Decreased 2 to 3 times.	25
Dromus B plus Esso 1 ¹¹	5 - 7	Bit life.....	Increased very markedly	} 9
		Drilling rate...	...do.....	
		Rod grease.....	Not required.....	
Kerosine ⁷	Pure	Bit friction...	Decreased 7 times.....	} 25
		Bit wear.....	Decreased 40 times.....	
Magnesium chloride ⁷	.01 - .05	Drilling rate...	Increased.....	} 6
		Rock hardness...	Decreased.....	
Do. ⁷	.1 - .5	Bit wear.....	Decreased 10 to 35 pct.	} 26
		Drilling rate...	Increased 20 to 60 pct.	
n-alcohols ⁸	NA	...do.....	Increased 20-fold.....	8
		...do.....	NE.....	29
Naphthenic acid soap ⁷	NA	Bit wear.....	Decreased 10 to 35 pct.	} 26
		Drilling rate...	Increased 20 to 60 pct.	
Naphthenic oil.....	.25 - .5	Bit life.....	Increased.....	} 30
		Bit wear.....	Decreased.....	
		Drilling rate...	Increased.....	
		Rock hardness...	Decreased.....	
		Rock strength...	Decreased 9 to 20 pct..	

See notes at end of table.

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type--Con.

Additive ¹	Concentrations tested, wt pct ²	Property	Effect ³	References ⁴
QUARTZ--Continued				
Naphthenic oil plus sodium carbonate.	0.25 .25	Bit life..... Bit wear..... Drilling rate... Rock hardness... Rock strength...	Increased..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..	30
Oleylammonium acetate ⁸	.7	Drilling rate...	Increased 50 pct.....	
Petroleum sulfonate ⁷	0.25 - .5	Bit wear..... Drilling rate...	Decreased 10 to 35 pct. Increased 20 to 60 pct.	
Potassium chloride ⁷	.01 - .5	Bit wear..... Drilling rate...	Decreased 10 to 35 pct. Increased 20 to 60 pct.	
Sodium carbonate ⁷	.01 - .1	...do..... Rock hardness...	Increased..... Decreased.....	
Sodium chloride ⁷	.1 - .5	Bit life..... Bit wear..... Drilling rate... Rock hardness... Rock strength...	Increased..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Decreased..... Decreased 9 to 20 pct..	30 26, 30 26, 30 30 30
Do. ⁷	.1	Drilling rate... Rock hardness...	Increased..... Decreased.....	6
Sodium hydroxide ⁷	.1 - 1.0	Bit wear..... Drilling speed..	Decreased 10 pct..... Increased 20 pct.....	18
Sodium oleate ⁷	NA	Bit wear.....	Decreased 2 to 3 times.	25
Sodium orthophosphate ⁷	1.0 - 2.0	...do..... Drilling speed.. Rock hardness...	Decreased 10 pct..... Increased 20 pct..... Decreased 60 to 70 pct.	18
Sodium pyrophosphate ⁷	1.0 - 2.0	Bit wear..... Drilling speed.. Rock hardness...	Decreased 10 pct..... Increased 20 pct..... Decreased 60 to 70 pct.	18
Sugar ⁷	.1 - 1.0	Drilling rate... Rock hardness...	Increased..... Decreased.....	6
Toluene ⁸	Pure	Drilling rate...	Increased 20-fold.....	8
Water ^{8,25}	NAP			
DTAB ⁸mol/L..	10 ⁻⁴ - 10 ⁻³	Bit life..... Drilling costs.. Drilling rate...	Increased 4-fold..... Reduced..... Increased 20-fold.....	15 15 8
QUARTZITE				
Aluminum chloride ^{7,23}	0.1 - 0.15	Amount drilled.. Bit wear..... Drilling rate... Drilling speed..	Increased..... Decreased 26 pct..... Increased..... ...do.....	19
Anionic detergent ⁸	4, 8, 12	Bit energy..... Bit friction.... Bit life..... Bit wear..... Drilling costs.. Drilling rate... Overall efficiency.	...do..... ...do..... ...do..... Decreased..... Decreased 30 pct..... Increased..... Increased 60 pct.....	28 28 21, 27 28 27 21, 28 20
Dromus B ¹¹	34.91 35.13	Bit life..... Bit wear..... Drilling rate... Drill vibration. Lifting action.. Pump pressures..	Increased very markedly Decreased..... Increased very markedly Eliminated..... Improved..... Reduced.....	9 9-10 9-10 10 10 10

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type--Con.

Additive ¹	Concentrations tested, wt pct ²	Property	Effect ³	References ⁴
QUARTZITE--Continued				
Ethylene glycol ⁸	4, 8, 12	Bit energy.....	Increased.....	28
		Bit friction....	...do.....	28
		Bit life.....	...do.....	21, 27
		Bit wear.....	Decreased.....	28
		Drilling costs..	Decreased 30 pct.....	27
		Drilling rate...	Increased.....	21, 28
Ferric chloride ^{7,23}	.48	Amount drilled..	Increased.....	} 19
		Bit wear.....	Decreased 26 pct.....	
		Drilling rate...	Increased.....	
		Drilling speed..	...do.....	
Glycerine ⁸	4, 8, 12	Bit energy.....	...do.....	28
		Bit friction....	...do.....	28
		Bit life.....	...do.....	21, 27
		Bit wear.....	Decreased.....	28
		Drilling costs..	Decreased 30 pct.....	27
		Drilling rate...	Increased.....	21, 28
Magnesium chloride ^{7,23}	.3	Amount drilled..	...do.....	} 19
		Bit wear.....	Decreased 26 pct.....	
		Drilling rate...	Increased.....	
		Drilling speed..	...do.....	
Mobil 1535 ²¹	4.0	Bit life.....	} NE.....	9
		Drilling rate...		
Sodium chloride ^{7,23}	.25	Amount drilled..	Increased.....	} 19
		Bit wear.....	Decreased 26 pct.....	
		Drilling rate...	Increased.....	
		Drilling speed..	...do.....	
Solvac ²¹	1.0	Bit life.....	Increased very markedly	} 9
		Drilling rate...	...do.....	
Water ^{8,25}	NAP	NP.....	NE.....	21
Aerosol C-61 ⁸mol/L..	10 ⁻³	Bit life.....	Increased 4 times.....	} 13-14
		Bit wear.....	Decreased 4.8 times....	
		Drilling rate...	Increased.....	
RHYOLITE AND PORPHYRY				
RHYOLITE ²²				
B.P.S.B.4.....	2.5	Bit life.....	Increased very markedly	9
RHYOLITE PORPHYRY ⁸				
Conco-XAC.....	.032	} NP.....	NE.....	15
Conco-XAM.....	>1.0			
Consoft C.....	<.001			
Consoft CP-50.....	.0016			
Duomac T.....	<.001			
Hetoxamine C-10.....	.0016			
Intersoft 49.....	.001			
Marvansoft FBH.....	.25	Bit life.....	Increased 5-fold.....	} 15
		Drilling costs..	Decreased 50 pct.....	
Marvansoft FMA.....	.025	} NP.....	NE.....	15
Solar CL-385.....	<.001			
Torque trim.....	2.0			
Aerosol C-61 ³⁶mol/L..	10 ⁻⁴ - 10 ⁻³	Bit life.....	Increased.....	} 13
		Bit wear.....	Decreased.....	
PORPHYRY				
Mobil 1535 ²¹	4.0	NP.....	NE.....	9
Sodium chloride ⁷	.1 - .25	Amount drilled..	Increased.....	} 19
		Drilling rate...	...do.....	
		Drilling speed..	...do.....	
		Dust.....	Decreased.....	

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type--Con.

Additive ¹	Concentrations tested, wt pct ²	Property	Effect ³	References ⁴	
RIEBECKITES ⁷					
Dromus B.....	0.91	Bit wear..... Drilling rate... Drill vibration. Lifting action.. Pump pressures..	Decreased..... Increased..... Eliminated..... Improved..... Reduced.....	9	
SANDSTONE					
Aluminum chloride.....	0.3	Bit wear..... Drilling rate... Dust.....	Decreased 28 to 42 pct ⁸ Increased ⁷ Decreased ⁷	19	
Do. ⁸	0.0 - .5	Bit wear..... Drilling rate...	...do..... Increased 15 to 40 pct.		23
Do. ⁸	.0075- .03	Drill thrust.... Rock hardness...	Reduced..... Decreased.....		
B.P.S.B. ⁴²²	2.5	Bit life.....	Increased very markedly	9	
Calcium hydroxide.....	.05 - .07	...do..... Bit wear..... Drilling rate... Rock hardness... Rock strength...	Increased..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..	30	
Hydrochloric acid ⁸	.0 - .5	Bit wear..... Drilling rate...	Decreased..... Increased 15 to 40 pct.		23
Lime.....	.05 - .07	Bit wear..... Drilling rate...	Decreased 10 to 35 pct. Increased 20 to 60 pct.		
Magnesium chloride ⁸	.0 - .3	Bit life..... Bit wear..... Drilling rate...	Increased..... Decreased..... Increased 15 to 40 pct.		19 19 23
Mud: ⁸					
Bentonite clay.....	5.6	} Bit wear.....	Reduced.....	7	
Sodium bicarbonate.....	.95				
Sodium chloride.....	13.4				
Tap water.....	80.05				
Oil soap ⁷	.1	Drilling rate... Dust.....	Increased..... Decreased.....	19	
SMAD 1 ⁷	NA	Bit friction.... Rock strength... Torsional moment	...do..... ...do..... ...do.....		5
Sodium carbonate.....	.25	Bit life..... Bit wear..... Drilling rate... Rock hardness... Rock strength...	Increased..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..	30	
Do.....	.3 - .5	Bit wear..... Drilling costs.. Drilling speed.. Dust.....	Decreased 2.5 times.... Slightly reduced..... Increased 4 times..... Decreased.....		19
Do. ⁸	.0 - .5	Bit wear..... Drilling rate...	Reduced..... Increased 15 to 40 pct.		
Sodium chloride.....	.25	Amount drilled ⁸ . Bit life..... Bit wear..... Drilling rate... Drilling speed ⁸ . Rock hardness... Rock strength...	Increased..... ...do..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Increased..... Decreased..... Decreased 9 to 20 pct..		19, 26, 30 19 30 30 30
Do. ⁸	.0 - 3.5	Bit wear..... Drilling rate...	Decreased..... Increased 15 to 40 pct.		

TABLE 1. - Effects of chemical additives on rock and drilling properties, by rock type--Con.

Additive ¹	Concentrations tested, wt pct ²	Property	Effect ³	References ⁴
SANDSTONE--Continued				
Sodium chloride plus sodium carbonate.	0.25	Bit life.....	Increased.....	30
	.25	Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
Sulfanol ⁷	0.05 - .15	Bit energy.....	Decreased.....	} 5
		Bit friction....	...do.....	
		Drilling rate...	Increased.....	
		Rock strength...	Decreased.....	
Sulfate soap ⁷	NA	Bit friction....	...do.....	} 5
		Rock strength...	...do.....	
		Torsional moment	...do.....	
Thorium chloride ⁸	.0 - .03	Bit wear.....	Reduced.....	} 23
		Drilling rate...	Increased 15 to 40 pct.	
SERPENTINE ⁸				
Aluminum chloride.....	0.0001- 1.0	NP.....	NE.....	2
SIDERITE ⁷				
Calcium hydroxide.....	0.05 - 0.07	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
Sodium carbonate.....	.25	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate...	Increased 20 to 60 pct.	26, 30
		Rock hardness...	Decreased.....	30
		Rock strength...	Decreased 9 to 20 pct..	30
TUFF ²²				
B.P.S.B.4.....	2.5	Bit life.....	Increased very markedly	9

NA Not available. NAP Not applicable.

NE No added effect reported. NP No specific property reported.

¹Reference to specific products does not imply endorsement by the Bureau of Mines.²Concentrations are given in weight percent unless otherwise indicated.³Compared to drilling with water alone.⁴Numbers refer to items in the list of references preceding the appendixes.⁵Field test using AXL (1.185-in-ID) bit. ⁶Optimum reported concentration.⁷Field test(s), no bit size given. ⁸Laboratory test(s).⁹Compared to dry drilling, not to water.¹⁰Optimum reported concentration was 0.01 pct.¹¹Field test using NX (3.0-in-ID) bit. ¹²Hard shales.¹³Soft shales. ¹⁴Very soft shales.¹⁵Optimum reported concentration was 0.25 pct.¹⁶Optimum reported concentration was 0.1 pct.¹⁷Hard chert. ¹⁸Soft chert.¹⁹Novo Khazinskii and Arlanskii coal deposits, Arlansk region, field tests.²⁰New South Wales coal measure, field tests. ²¹Field test using AX (1.91-in-ID) bit.²²Field test using BX (2.375-in-ID) bit and NX (3.0-in-ID) bit.²³Industrial tests. ²⁴Field test using EX (1.5-in-ID) bit.²⁵Water used as drilling fluid, not just for comparison purposes.²⁶Tests on hematite and taconite. ²⁷Recommended for all low-silica, igneous rocks.²⁸Hard ironstone. ²⁹Soft ironstone.³⁰Field tests using AX (1.91-in-ID) bit and BX (2.375-in-ID) bit. ³¹Jaspilite.³²Reported that the reactant fluid, calcium chloride, produced the enhanced results.³³Using hexadecane produced the enhanced results.³⁴Hard quartzite. ³⁵Soft quartzite.³⁶Using BX (2.375-in-ID) bit.

Mud
 (formula, in percent:
 Bentonite clay..... 5.6
 Sodium bicarbonate..... .95
 Sodium chloride..... 13.4
 Tap water..... 80.05)
 n-alcohols ($C_nH_{2n+1}OH$)
 n-alkanes (C_nH_{2n+2})
 Naphthenic acid soap
 Naphthenic acid soap plus sodium
 carbonate
 Naphthenic oil
 Naphthenic oil plus sodium carbonate
 Oil soap
 Oleylammonium acetate ($C_{18}H_{35}NH_3C_3H_7O_2$)
 OP-10 (nonionic surfactant)
 Petroleum sulfonate
 Potassium chloride (KCl)
 Quat 316 (dodecylethyldimethyl ammonium
 bromide) ($C_{17}H_{36}NH_3Br$)
 SMAD (surfactant)
 SNS (surfactant)
 Soap (unspecified)
 Sodium carbonate (Na_2CO_3)
 Sodium carbonate plus soap
 Sodium chloride (NaCl)
 Sodium chloride plus sodium carbonate
 Sodium hydroxide (NaOH)

Sodium hydroxide plus sodium carbonate
 Sodium oleate ($NaC_{18}H_{33}O_2$)
 Sodium orthophosphate (Na_5PO_4)
 Sodium phosphate (Na_3PO_4)
 Sodium pyrophosphate ($Na_4P_2O_7$)
 Sodium silicate (Na_2SiO_3)
 Solar CL-385 (surfactant)
 Solvac (soluble oil)
 Sugar ($C_{12}H_{22}O_{11}$)
 Sulfanol (surfactant)
 Sulfate soap (surfactant)
 Sulfite cellulose lye (byproduct of pa-
 per manufacturing)
 Sulfonaphthenic petroleum acids (by-
 product of paper manufacturing)
 Tergitol 7 (sodium heptadecyl surfac-
 tant) ($NaC_{16}H_{33}SO_4$)
 Tergitol NPX (36-carbon nonionic sur-
 factant, nonylphenol-polyethylene
 oxide)
 Thorium chloride ($ThCl_4$)
 Toluene (C_7H_8)
 Torque trim (surfactant)
 Water (H_2O)

Table 2 summarizes the results of the
 drilling tests in the same manner as ta-
 ble 1, but by order of chemical additive
 rather than rock type.

DISCUSSION

This literature survey was pursued to
 catalog the diversity of chemical addi-
 tives and to report on the wide vari-
 ations that have been found in their
 ability to increase efficiency in drill-
 ing. Many different chemical-rock com-
 binations were tested, many at several
 chemical concentration levels. The re-
 search results reported in the literature
 dealt with the effect of chemical addi-
 tives on rocks in such areas as rock
 hardness, bit wear, electrochemical ef-
 fects, and drilling penetration rates.
 These results were used as a starting
 point for laboratory testing now going
 on in the Bureau to determine the basic

reason why some fluids worked for some
 chemical-rock combination at a given con-
 centration in some, but not all, areas of
 application.

Experimental laboratory drilling tests
 are being performed with several chemi-
 cal-rock combinations, in conjunction
 with studies of rock hardness changes,
 surface modification effects, bit wear
 rates, and penetration rates. These lab-
 oratory studies are being done to gain a
 better understanding of enhanced drilling
 and to give drilling technologists some
 guidelines for choosing the best chemical
 additive for a given drilling task.

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²
AEROSOLS				
AEROSOL ³				
Greenstone.....	0.8	Drilling effectiveness.	Increased.....	11
AEROSOL C-61 ⁴				
Granite.....	⁵ 10 ⁻⁴ - 10 ⁻²	Bit life.....	Increased 4 to 5 times.	12, 14, 16, 18
		Bit wear.....	Decreased 4.8 times....	
		Drilling rate..	Increased.....	
Hematite ⁶	⁵ 10 ⁻⁴ - 10 ⁻²	Bit life.....	Increased 5-fold.....	13
		Bit wear.....	Decreased 4.8 times....	
Quartzite.....	⁵ 10 ⁻³	Bit life.....	Increased 4 times.....	13-14
		Bit wear.....	Decreased 4.8 times....	
		Drilling rate..	Increased.....	
Rhyolite porphyry ⁷	⁵ 10 ⁻⁴ - 10 ⁻³	Bit life.....	...do.....	13
		Bit wear.....	Decreased.....	
AEROSOL OT ⁴				
Granite.....	⁵ 10 ⁻³ - 10 ⁻²	NP.....	NE.....	14
ALUMINUM CHLORIDE				
Anhydrite ⁸	0.01 - 1.0	Bit wear.....	Decreased 10 pct.....	18
		Drilling speed.	Increased 20 pct.....	
Argillaceous rocks (shales).....	.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased.....	
		Drilling rate..	Increased.....	
		Rock hardness..	Reduced.....	
		Rock strength..	Decreased 9 to 20 pct..	
Do. ^{4,9}	¹⁰ .0 - .05	Bit wear.....	Reduced.....	23
		Drilling rate..	Increased 15 to 40 pct.	
Do. ^{4,9}	.0075- .03	Drill thrust...	Reduced.....	24
		Rock hardness..	...do.....	
Calcium fluoride crystals ⁴	NA	NP.....	NE.....	31
Diabase ⁸	.17 - .22	Drilling costs.	Decreased.....	19
		Drilling rate..	Significantly increased	
Diorite ⁸	.02	...do.....	NE.....	19
Granite ⁴	.05	Amount drilled.	Increased.....	19
		Drilling rate..	...do.....	
		Drilling speed.	...do.....	
Do. ⁴	⁵ 3 x 10 ⁻⁶	Bit wear.....	Minimized.....	1, 14
		Rock hardness..	Maximized.....	
Granodiorite.....	.01 - .05	Drilling rate..	Increased.....	6
		Rock hardness..	Minimized.....	
Do.....	¹¹ .005	...do.....	...do.....	3
Gritstone ^{4,8}	.0 - .05	Drilling rate..	Increased 15 to 40 pct.	23
Do. ^{4,8}	.0075- .03	Drill thrust...	Reduced.....	23
		Rock hardness..	...do.....	
Hematite.....	.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	26, 30
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct..	30
Igneous rocks ¹²	.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased.....	
		Drilling rate..	Increased.....	
		Rock hardness..	Decreased.....	
		Rock strength..	Decreased 9 to 20 pct..	
Ironstone ⁸	.1 - .15	Amount drilled.	Increased.....	19
		Bit wear.....	Decreased 26 pct.....	
		Drilling rate..	Increased.....	
		Drilling speed.	...do.....	
Limestone ^{4,9}	.0 - .5	Bit wear.....	Reduced.....	23
		Drilling rate..	Increased 9 pct.....	

See notes at end of table.

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type--Con.

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²
ALUMINUM CHLORIDE--Continued				
Magnesite.....	0.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	26, 30
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct..	30
Magnesium oxide crystals ⁴	NA	Drilling rate..	Increased.....	32
Marble ⁴	0.5 - 1.0	...do.....	NE.....	2
Martite.....	.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	26, 30
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct..	30
Microcline ⁴	.0001- 1.0	NP.....	NE.....	29
Pyrite.....	.1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	26, 30
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct..	30
Quartz ⁸	.01 - .05	Drilling rate..	Increased.....	} 6
		Rock hardness..	Decreased.....	
Do. ⁸	.02 - .1	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	26, 30
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct..	30
Do. ⁸	.7 - 1.0	Amount drilled.	Increased.....	} 19
		Bit wear.....	Decreased 34 pct.....	
		Drilling speed.	Increased.....	
Quartzite ^{8, 13}	.1 - .15	Amount drilled.	...do.....	} 19
		Bit wear.....	Decreased 26 pct.....	
		Drilling rate..	Increased.....	
		Drilling speed.	...do.....	
Sandstone.....	.3	Bit wear.....	Decreased 28 to 42 pct ⁴	} 19
		Drilling rate..	Increased ⁸	
		Dust.....	Decreased ⁸	
Do. ⁴	.0 - .5	Bit wear.....	...do.....	} 23
		Drilling rate..	Increased 15 to 40 pct.	
Do. ⁴	.0075- .03	Drill thrust...	Reduced.....	} 24
		Rock hardness..	Decreased.....	
Serpentine ⁴	.0001- 1.0	NP.....	NE.....	2
AMMONIUM NITRATE ⁸				
Granite.....	0.02	Amount drilled.	Increased.....	} 19
		Bit corrosion..	Extreme.....	
		Drilling rate..	Increased.....	
		Drilling speed.	...do.....	
ANIONIC DETERGENT ⁴				
Quartzite.....	4, 8, 12	Bit energy.....	Increased.....	28
		Bit friction...	...do.....	28
		Bit life.....	...do.....	21, 27
		Bit wear.....	Decreased.....	28
		Drilling costs.	Decreased 30 pct.....	27
		Drilling rate..	Increased.....	21, 28
		Overall efficiency.	Increased 60 pct.....	20
B.P.S.B. ^{4 14}				
Granite.....	} 2.5	Bit life.....	Increased very markedly	9
Quartz.....				
Rhyolite.....				
Sandstone.....				
Tuff.....				

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type--Con.

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²
CALCIUM CHLORIDE				
Anhydrite ⁸	0.1 - 1.0	Bit wear..... Drilling speed.	Decreased 10 pct..... Increased 20 pct.....	18
Limestone.....	1.0	Amount drilled. Drilling rate.. Drilling speed.	Increased..... ...do..... ...do.....	
CALCIUM HYDROXIDE				
Anhydrite.....	¹⁵ 0.06	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..	18, 30
Limestone.....	0.05 - .07	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..	
Sandstone.....	.05 - .07	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..	30
Siderite ⁸	.05 - .07	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Decreased..... Decreased 9 to 20 pct..	
COMPOUND "M" ³				
Greenstone.....	0.2	Drilling effectiveness.	Increased.....	11
CONCO XAC, CONCO XAM, CONSOFT C, CONSOFT CP-50 ⁴				
CONCO XAC Rhyolite porphyry.....	0.032	} NP.....	NE.....	15
CONCO XAM Rhyolite porphyry.....	>1.0			
CONSOFT C Rhyolite porphyry.....	<.001			
CONSOFT CP-50 Rhyolite porphyry.....	.0016			
CUTALL OIL ³				
Greenstone.....	20.0	Drilling effectiveness.	Increased.....	11
DIMETHYLFORMAMIDE (DMF), DIMETHYLSULFOXIDE (DMSO), DMF IN DMSO ⁴				
DMF				
Calcium fluoride crystals.....	0 -100	Rock hardness..	Reduced.....	31-32
Lithium fluoride crystals ⁹	NA	Bit life.....	Increased.....	13
Magnesium oxide crystals.....	0 -100	Drilling rate..	...do.....	15, 32
DMSO				
Calcium fluoride crystals.....	0 -100	Rock hardness..	Reduced.....	31-32
Magnesium oxide crystals.....	0 -100	Drilling rate..	Increased.....	32
DMF IN DMSO				
Calcium fluoride crystals.....	0 - 50	Rock hardness..	Reduced.....	31-32
Magnesium oxide crystals.....	50	Drilling rate..	Increased 20 times....	8, 32
		Rock hardness..	Decreased.....	31
DISOLVANE 4411				
Coal ¹⁶	NA	NP.....	NE.....	22
DODECYLAMINO ACETATE ⁸				
Quartz.....	NA	Bit wear.....	Decreased 2 to 3 times.	25
See notes at end of table.				

See notes at end of table.

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type--Con.

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²
DODECYLTRIMETHYL AMMONIUM BROMIDE (DTAB)				
Granite ⁴	⁵ 10 ⁻⁴ - 10 ⁻³	Bit life..... Drilling costs. Drilling rate..	Increased..... Reduced..... Increased 3 to 4 times.	} 8, 12, 14- 15, 17, 32
Microcline.....	⁵ 10 ⁻⁴ - 10 ⁻³	...do.....	Increased.....	
Quartz ⁴	⁵ 10 ⁻⁴ - 10 ⁻³	Bit life..... Drilling costs. Drilling rate..	Increased 4-fold..... Reduced..... Increased 20-fold.....	
DROMUS B				
Argillaceous rocks: ¹⁷				
Hard shales.....	0.91	Bit life.....	Increased very markedly	} 9
Soft shales.....	.13	Drilling rate..	...do.....	
Hard shales.....	.67	Bit wear.....	Reduced.....	} 10
Very soft shales.....	.17	Drilling rate..	Increased.....	
		Drill vibration	Eliminated.....	
		Lifting action.	Improved.....	
		Pump pressures.	Reduced.....	
Chert: ¹⁷				
Hard.....	.91	Bit life.....	Increased very markedly	} 9
Soft.....	.13	Drilling rate..	...do.....	
		Rod grease.....	Not required.....	
Coal ¹⁸	1.0	Bit life..... Drilling rate.. Rod grease.....	Increased markedly.... Increased slightly.... Required.....	} 9
Dolomite ¹⁷	0.13 - .91	Bit life..... Drilling rate.. Rod grease.....	Increased markedly.... ...do..... Not required.....	
Do. ⁸	.67	Bit wear..... Drilling rate.. Drill vibration Lifting action. Pump pressures.	Decreased..... Increased..... Eliminated..... Improved..... Reduced.....	} 10
Ironstone: ¹⁷				
Hard.....	.91	Bit life.....	Increased very markedly	
Soft.....	.13	Bit wear.....	Decreased.....	
		Drilling rate..	Increased very markedly	
		Drill vibration	Eliminated.....	9
		Lifting action.	Improved.....	9-10
		Pump pressures.	Reduced.....	10
Ironstone (jaspilite) ¹⁹	NA	Bit life..... Drilling rate.. Rod grease.....	Increased very markedly Increased markedly.... Not required	} 9
Quartzite: ¹⁷				
Hard.....	.91	Bit life.....	Increased very markedly	9
Soft.....	.13	Bit wear.....	Decreased.....	9-10
		Drilling rate..	Increased very markedly	9-10
		Drill vibration	Eliminated.....	10
		Lifting action.	Improved.....	10
		Pump pressures.	Reduced.....	10
Riebeckites ⁸	.91	Bit wear..... Drilling rate.. Drill vibration Lifting action. Pump pressures.	Decreased..... Increased..... Eliminated..... Improved..... Reduced.....	} 9
DROMUS B PLUS ESSO 1 ¹⁷				
Chert.....	5 - 7	Bit life..... Drilling rate.. Rod grease.....	Increased very markedly ...do..... Not required.....	} 9

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type--Con.

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²	
DROMUS B PLUS ESSO 1--Continued ¹⁷					
Granite.....	5 - 7	Bit life..... Drilling rate..	Increased very markedly ...do.....	9	
Quartz.....	5 - 7	Bit life..... Drilling rate.. Rod grease.....	...do..... ...do..... Not required.....		9
DUOMAC T ⁴					
Rhyolite porphyry.....	<0.001	NP.....	NE.....	15	
ETHYL ALCOHOL					
Dolomite.....	NA	Drilling rate..	Increased 70 pct.....	20	
ETHYLENE GLYCOL ⁴					
Quartzite.....	4, 8, 12	Bit energy..... Bit friction... Bit life..... Bit wear..... Drilling costs. Drilling rate..	Increased..... ...do..... ...do..... Decreased..... Decreased 30 pct..... Increased.....	28 28 21, 27 28 27 21, 28	
FERRIC CHLORIDE					
Hematite.....	0.1	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Decreased..... Decreased 9 to 20 pct..	30 26, 30 26, 30 30 30	
Magnesite.....	.1	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Decreased..... Decreased 9 to 20 pct..	30 26, 30 26, 30 30 30	
Martite.....	.1	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Decreased..... Decreased 9 to 20 pct..	30 26, 30 26, 30 30 30	
Pyrite.....	.1	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Decreased..... Decreased 9 to 20 pct..	30 26, 30 26, 30 30 30	
Quartzite ^{8, 13}	.48	Amount drilled. Bit wear..... Drilling rate.. Drilling speed.	Increased..... Decreased 26 pct..... Increased..... ...do.....	19	
GLYCERINE ⁴					
Quartzite.....	4, 8, 12	Bit energy..... Bit friction... Bit life..... Bit wear..... Drilling costs. Drilling rate..	Increased..... ...do..... ...do..... Decreased..... Decreased 30 pct..... Increased.....		28 28 21, 27 28 27 21, 28
HETOXAMINE C-10 ⁴					
Rhyolite porphyry.....	0.0016	NP.....	NE.....	15	
HYDROCHLORIC ACID					
Argillaceous rocks (shales) ⁴	0.0 - 0.5	Bit wear..... Drilling rate..	Reduced..... Increased 15 to 40 pct.	23	
Dolomite.....	<1.0	Bit wear..... Drilling speed. Rock hardness..	Decreased 10 pct..... Increased 20 pct..... Decreased 80 pct.....		18
Gritstone ^{4, 9}	.0 - .5	NP.....	NE.....	23	
Limestone ^{8, 20}	1.0	Bit wear..... Drilling speed.	Decreased 10 pct..... Increased 10 to 70 pct.	18	

See notes at end of table.

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type--Con.

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²
HYDROCHLORIC ACID--Continued				
Limestone ²⁰	0.1 - 0.3	Amount drilled. Drilling rate.. Drilling speed.	Increased..... ...do..... ...do.....	} 19
Do. ^{4,9,20}	.0 - .5	Bit wear..... Drilling rate.. Drilling speed.	Reduced..... Increased 9 pct..... Increased 15 to 40 pct.	
Sandstone ⁴	.0 - .5	Bit wear..... Drilling rate.. Drilling speed.	Decreased..... Increased 15 to 40 pct. Increased 15 to 40 pct.	
INTERSOFT 49 ⁴				
Rhyolite porphyry.....	0.001	NP.....	NE.....	15
KEROSENE				
Greenstone ³	Pure	Drilling effectiveness.	Increased.....	11
Quartz ⁸	Pure	Bit friction... Bit wear.....	Decreased 7 times..... Decreased 40 times.....	} 25
LIME				
Sandstone.....	0.05 - 0.07	Bit wear..... Drilling rate.. Drilling speed.	Decreased 10 to 35 pct. Increased 20 to 60 pct. Increased 20 to 60 pct.	} 26
MAGNESIUM CHLORIDE				
Argillaceous rocks (shales) ⁴	0.0 - 0.3	Bit wear..... Drilling rate.. Drilling speed.	Reduced..... Increased 15 to 40 pct. Increased 15 to 40 pct.	} 23
Diabase ⁸	.75 - 1.5	Drilling costs. Drilling rate.. Drilling speed.	Decreased..... Slightly increased..... Slightly increased.....	
Granite ¹³	.01	Amount drilled. Drilling rate.. Drilling speed.	Increased..... ...do..... ...do.....	} 19
Granodiorite.....	.01 - .05	Drilling rate.. Rock hardness.. Drilling rate.. Drilling speed.	...do..... Minimized..... Increased..... Increased.....	
Do. ^{8,13}	.9 - 1.5	Drilling rate.. Rock hardness.. Drilling rate.. Drilling speed.	Increased..... Minimized..... Increased..... Increased.....	} 19
Do.....	11.05	Rock hardness.. Drilling rate.. Drilling speed.	Minimized..... Increased..... Increased.....	
Gritstone ^{4,9}	.0 - .3	NP.....	NE.....	23
Ironstone ⁸	.3	Amount drilled. Bit wear..... Drilling rate.. Drilling speed.	Increased..... Decreased 26 pct..... Increased..... ...do.....	} 19
Limestone.....	21.25 - 1.0	Amount drilled. Drilling rate.. Drilling speed.	...do..... ...do..... ...do.....	
Do. ^{4,9}	.0 - .3	Bit wear..... Drilling rate.. Drilling speed.	Reduced..... Increased 9 pct..... Increased 9 pct.	} 23
Marble ⁴	NA	...do.....	NE.....	
Microcline ⁴	.0001- 1.0	NP.....	NE.....	29
Quartz ⁸	.01 - .5	Drilling rate.. Rock hardness.. Drilling rate.. Drilling speed.	Increased..... Decreased..... Increased..... Increased.....	} 6
Do. ⁸	.1 - .5	Bit wear..... Drilling rate.. Drilling speed.	Decreased 10 to 35 pct. Increased 20 to 60 pct. Increased 20 to 60 pct.	
Quartzite ^{8,13}	.3	Amount drilled. Bit wear..... Drilling rate.. Drilling speed.	Increased..... Decreased 26 pct..... Increased..... Increased.....	} 19
Sandstone ⁴	.0 - .3	Bit life..... Bit wear..... Drilling rate.. Drilling speed.	...do..... Decreased..... Increased 15 to 40 pct. Increased 15 to 40 pct.	
MAGNESIUM SULFATE				
Diabase ⁸	0.25	Drilling costs. Drilling rate.. Drilling speed.	Decreased..... Slightly increased..... Slightly increased.....	} 19
Limestone.....	0.75 - 1.0	Amount drilled. Drilling rate.. Drilling speed.	Increased..... ...do..... ...do.....	

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type--Con.

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²
MARVANSOFT FBH, MARVANSOFT FMA ⁴				
MARVANSOFT FBH Rhyolite porphyry.....	0.25	Bit life..... Drilling costs..	Increased 5-fold..... Decreased 50 pct.....	15
MARVANSOFT FMA Rhyolite porphyry.....	.025	NP.....	NE.....	
MOBIL 1535 ²²				
Greenstone.....	4.0	Bit life..... Drilling rate..	NE.....	9
Porphyry.....	4.0	NP.....		
Quartzite.....	4.0	Bit life..... Drilling rate..		
MUD ⁴				
Granite..... Limestone..... Marble..... Sandstone.....	(23)	Bit wear.....	Reduced.....	7
N-ALCOHOLS				
Granite.....	(24)	NP.....	NE.....	12, 32
Quartz ⁴	NA	Drilling rate.. ...do.....	Increased 20-fold..... NE.....	8 29
N-ALKANES ⁴				
Calcium fluoride crystals.....	NA	Drilling rate..	Increased.....	31
Magnesium oxide crystals.....	NA	...do.....	Increased 8 times using hexadecane.	20, 32
NAPHTHENIC ACID SOAP				
NAPHTHENIC ACID SOAP ⁸ Quartz.....	NA	Bit wear..... Drilling rate..	Decreased 10 to 35 pct. Increased 20 to 60 pct.	26
NAPHTHENIC ACID SOAP PLUS SODIUM CARBONATE ²⁵ Granite.....	¹⁵ 0.25 - 0.5 .25	Bit wear..... Drilling rate..	Decreased 10 to 35 pct. Increased 20 to 60 pct.	
NAPHTHENIC OIL				
NAPHTHENIC OIL Quartz.....	0.25 - 0.5	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..	30
NAPHTHENIC OIL PLUS SODIUM CARBONATE Quartz.....	²⁶ .25	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..	
OIL SOAP				
Limestone.....	0.1 - 1.0	Amount drilled. Drilling rate.. Drilling speed.	Increased..... ...do..... ...do.....	19
Sandstone ⁸	.1	Drilling rate.. Dust.....	...do..... Decreased.....	
OLEYLAMMONIUM ACETATE				
Amygdaloidal basalt ²⁷	¹⁵ 0.01	Drilling costs. Drilling rate..	Reduced..... Increased 20 to 50 pct.	4
Quartz ⁴	.7	...do.....	Increased 50 pct.....	
See notes at end of table.				

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type--Con.

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²	
OP-10					
Coal ¹⁶	0.05 - 0.12	Bit life..... Bit wear..... Drilling rate..	Increased..... Decreased..... Increased.....	} 22	
PETROLEUM SULFONATE ⁸					
Quartz.....	0.25 - 0.5	Bit wear..... Drilling rate..	Decreased 10 to 35 pct. Increased 20 to 60 pct.	} 26	
POTASSIUM CHLORIDE ⁸					
Quartz.....	0.01 - 0.5	Bit wear..... Drilling rate..	Decreased 10 to 35 pct. Increased 20 to 60 pct.	} 26	
QUAT 316 ⁴					
Marble.....	⁵ 10 ⁻³ - 10 ⁻²	Drilling rate..	NE.....	2	
SMAD ⁸					
Argillaceous rocks (shales).....	NA	NA.....	NE.....	5	
Sandstone.....	NA	Bit friction... Rock strength.. Torsional moment.	Decreased..... ...do..... ...do.....	} 5	
SNS					
Coal ¹⁶	NA	NP.....	NE.....	22	
SOAP ⁴					
Marble.....	0.25 - 0.5	Drilling rate..	NE.....	2	
SODIUM CARBONATE					
Anhydrite ⁸	0.1 - 1.0	Bit wear..... Drilling speed.	Decreased 10 pct..... Increased 20 pct.....	} 18	
Argillaceous rocks: Shales.....	.25	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..		} 30
Do. ⁸	NA	Amount drilled. Drilling rate.. Drilling speed. Overall efficiency.	Slightly increased.... ...do..... ...do..... Increased.....		
Do. ⁴	²¹ .0 - .5	Bit wear..... Drilling rate..	Decreased..... Increased 15 to 40 pct.	} 23	
Argillites and schists.....	.1 - .25	Bit wear..... Drilling rate..	Decreased 10 to 35 pct. Increased 20 to 60 pct.		
Diabase ⁸	.75	Drilling costs. Drilling rate..	Decreased..... Slightly increased....	} 19	
Diorite ⁸	.5	...do.....	NE.....		
Granite ⁸	.25	Amount drilled. Drilling rate.. Drilling speed.	Increased..... ...do..... ...do.....	} 19	
Granodiorite.....	.01 - .1	Drilling rate.. Rock hardness..	...do..... Minimized.....		} 6
Gritstone ^{4,9}	.0 - .5	NP.....	NE.....	23	
Limestone ⁸	.25	Amount drilled. Bit life..... Bit wear..... Drilling rate.. Drilling speed. Rock hardness.. Rock strength..	Increased..... ...do..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Increased..... Decreased..... Decreased 9 to 20 pct..	} 19, 26, 30 19 30 30	
Do. ⁸	.1 - 1.0	Bit wear..... Drilling speed.	Decreased 10 pct..... Increased 10 to 70 pct.		

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type--Con.

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²
SODIUM CARBONATE--Continued				
Limestone ⁸	0.0 - 0.5	Amount drilled. Drilling rate.. Drilling speed.	Increased..... ...do..... ...do.....	19
Do. ^{4,9}	.0 - .5	Bit wear..... Drilling rate..	Reduced..... Increased 9 pct.....	
Marble ⁴	.2 - 1.0	...do.....	NE.....	
Quartz ⁸	.01 - .1	Drilling rate.. Rock hardness..	Increased..... Decreased.....	6
Sandstone.....	.25	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..	
Do.....	.3 - .5	Bit wear..... Drilling costs. Drilling speed. Dust.....	Decreased 2.5 times.... Slightly reduced..... Increased 4 times..... Decreased.....	19
Do. ⁴	.0 - .5	Bit wear..... Drilling rate..	...do..... Increased 15 to 40 pct.	
Siderite ⁸	.25	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Decreased..... Decreased 9 to 20 pct..	
SODIUM CARBONATE PLUS SOAP				
Igneous rocks ¹²	²⁶ 0.25	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased..... Increased..... Decreased..... Decreased 9 to 20 pct..	30
SODIUM CHLORIDE				
Anhydrite ⁸	0.1 - 1.0	Bit wear..... Drilling speed.	Decreased 10 pct..... Increased 20 pct.....	18
Argillaceous rocks: Shales, argillites and schists, clay rocks.	.25 - .5	Bit life..... Bit wear..... Drilling rate.. Rock hardness.. Rock strength..	Increased..... Decreased 10 to 35 pct. Increased 20 to 60 pct. Decreased..... Decreased 9 to 20 pct..	
Shales ⁸	.25	Amount drilled. Drilling rate.. Drilling speed. Overall efficiency.	Slightly increased.... ...do..... ...do..... Increased.....	19
Do. ⁸	1.0 - 2.0	Amount drilled. Drilling rate.. Drilling speed. Overall efficiency.	Slightly increased.... ...do..... ...do..... Increased.....	
Do. ⁴	²⁸ 0 - 3.5	Bit wear..... Drilling rate..	Reduced..... Increased 15 to 40 pct.	
Diabase ⁸	.4 - 1.0	Drilling costs. Drilling rate..	Decreased..... Slightly increased....	19
Diorite ⁸	.2	...do.....	Increased.....	
Granite ⁸	.1 - .5	Amount drilled. Drilling rate.. Drilling speed.	...do..... ...do..... ...do.....	19
Granodiorite ^{8,13}	1.0	Drilling rate..	...do.....	
See notes at end of table.				

See notes at end of table.

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type--Con.

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²
SODIUM CHLORIDE--Continued				
Granodiorite.....	0.1	Drilling rate..	Increased.....	6
		Rock hardness..	Minimized.....	
Do.....	¹¹ .05	...do.....	...do.....	3
Gritstone ^{4,9}	0.0 - 3.5	NP.....	NE.....	23
Hematite.....	.1 - .25	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	26, 30
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct..	30
Igneous rocks ¹²	.1 - .25	Bit life.....	Increased.....	30
		Bit wear.....	Decreased.....	
		Drilling rate..	Increased.....	
		Rock hardness..	Decreased.....	
		Rock strength..	Decreased 9 to 20 pct..	
Ironstone ⁸	.25	Amount drilled.	Increased.....	19
		Bit wear.....	Decreased 26 pct.....	
		Drilling rate..	Increased.....	
		Drilling speed.	...do.....	
Limestone ⁸	.25	Bit life.....	...do.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	26, 30
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct..	30
Do.....	.75	Amount drilled.	Increased.....	19
		Drilling rate..	...do.....	
		Drilling speed.	...do.....	
Do. ^{4,9}	28.0 - 3.5	Bit wear.....	Reduced.....	23
		Drilling rate..	Increased 9 pct.....	
Magnesite.....	.1 - .25	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	26, 30
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct..	30
Magnesium oxide crystals ⁴	¹¹ 10 ⁻²	Bit life.....	Increased 5 times.....	13
		Drilling rate..	Increased.....	8
Martite.....	.1 - .25	Bit life.....	...do.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	26, 30
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct..	30
Porphyry ⁸	.1 - .25	Amount drilled.	Increased.....	19
		Drilling rate..	...do.....	
		Drilling speed.	...do.....	
		Dust.....	Decreased.....	
Pyrite.....	.1 - .25	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	26, 30
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct..	30
Do. ^{4,8}	.1 - .5	Drilling speed.	Increased.....	19
Quartz ⁸	.1 - .5	Bit life.....	...do.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	26, 30
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct..	30
Do. ⁸	.1	Drilling rate..	Increased.....	6
		Rock hardness..	Decreased.....	
Quartzite ^{8,13}	.25	Amount drilled.	Increased.....	19
		Bit wear.....	Decreased 26 pct.....	
		Drilling rate..	Increased.....	
		Drilling speed.	...do.....	

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type--Con.

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²
SODIUM CHLORIDE--Continued				
Sandstone.....	0.25	Amount drilled ⁴	Increased.....	19
		Bit life.....	...do.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	19, 26, 30
		Drilling speed ⁴	Increased.....	19
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct..	30
Do. ⁴	0.0 - 3.5	Bit wear.....	Decreased.....	} 23
		Drilling rate..	Increased 15 to 40 pct.	
SODIUM CHLORIDE PLUS SODIUM CARBONATE				
Argillaceous rocks (clay rocks).	0.1 - 0.5	Bit life.....	Increased.....	} 30
		Bit wear.....	Decreased.....	
		Drilling rate..	Increased.....	
		Rock hardness..	Decreased.....	
		Rock strength..	Decreased 9 to 20 pct..	
Sandstone.....	26.25	Bit life.....	Increased.....	30
		Bit wear.....	Decreased 10 to 35 pct.	26, 30
		Drilling rate..	Increased 20 to 60 pct.	26, 30
		Rock hardness..	Decreased.....	30
		Rock strength..	Decreased 9 to 20 pct...	30
SODIUM HYDROXIDE				
Anhydrite.....	¹⁵ 0.05 - 0.1	Bit life.....	Increased.....	} 18, 30
		Bit wear.....	Decreased.....	
		Drilling rate..	Increased.....	
		Rock hardness..	Decreased.....	
		Rock strength..	Decreased 9 to 20 pct..	
Do. ⁸	.1 - .2	Amount drilled.	Increased.....	} 19
		Drilling rate..	...do.....	
		Drilling speed.	...do.....	
Limestone.....	.05	Bit life.....	Increased.....	} 30
		Bit wear.....	Decreased.....	
		Drilling rate..	Increased.....	
		Rock hardness..	Decreased.....	
		Rock strength..	Decreased 9 to 20 pct..	
Do.....	.1 - .2	Amount drilled.	Increased.....	} 19
		Drilling rate..	...do.....	
		Drilling speed..	...do.....	
Marble ⁴	.025 - .25	Drilling rate..	NE.....	2
Quartz ⁸	.1 - 1.0	Bit wear.....	Decreased 10 pct.....	} 18
		Drilling speed.	Increased 20 pct.....	
SODIUM HYDROXIDE PLUS SODIUM CARBONATE				
Dolomite.....	0.06 - 0.2	Amount drilled.	Increased.....	} 19
		Bit wear.....	Decreased 54 pct.....	
		Drilling rate..	Increased.....	
		Drilling speed.	Slightly increased....	
Limestone.....	.05 - .2	Amount drilled.	Increased.....	} 19
		Drilling rate..	...do.....	
		Drilling speed.	...do.....	
		Drilling speed.	...do.....	
SODIUM OLEATE ⁸				
Quartz.....	NA	Bit wear.....	Decreased 2 to 3 times.	25
SODIUM ORTHOPHOSPHATE ⁸				
Quartz.....	1.0 - 2.0	Bit wear.....	Decreased 10 pct.....	} 18
		Drilling speed.	Increased 20 pct.....	
		Rock hardness..	Decreased 60 to 70 pct.	
		Rock hardness..	Decreased 60 to 70 pct.	
SODIUM PHOSPHATE ⁸				
Limestone.....	0.1	Bit wear.....	Decreased 10 to 35 pct.	} 26
		Drilling rate..	Increased 20 to 60 pct.	

See notes at end of table.

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type--Con.

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²
SODIUM PYROPHOSPHATE ⁸				
Quartz.....	1.0 - 2.0	Bit wear..... Drilling speed. Rock hardness..	Decreased 10 pct..... Increased 20 pct..... Decreased 60 to 70 pct.	} 18
SODIUM SILICATE ⁸				
Limestone.....	0.025	Bit wear..... Drilling rate..	Decreased 10 to 35 pct. Increased 20 to 60 pct.	} 26
SOLAR CL-385 ⁴				
Rhyolite porphyry.....	<0.001	NP.....	NE.....	15
SOLVAC ²²				
Garnetite.....	1.0	Bit life..... Drilling rate.. Rod grease.....	Increased markedly..... Increased very markedly Not required.....	} 9
Quartzite.....	1.0	Bit life..... Drilling rate..	Increased very markedly ...do.....	
SUGAR				
Granodiorite.....	0.1 - 1.0	Drilling rate.. Rock hardness..	Increased..... Minimized.....	} 6
Quartz ⁸	.1 - 1.0	Drilling rate.. Rock hardness..	Increased..... Decreased.....	
SULFANOL ⁸				
Argillaceous rocks (shales).....	0.05 - 0.15	Bit energy..... Bit friction... Drilling rate.. Rock strength..	Decreased..... ...do..... Increased..... Decreased.....	} 5
Sandstone.....	.05 - .15	Bit energy..... Bit friction... Drilling rate.. Rock strength..	...do..... ...do..... Increased..... Decreased.....	
SULFATE SOAP ⁸				
Argillaceous rocks (shales).....	NA	NA.....	NE.....	5
Sandstone.....	NA	Bit friction... Rock strength.. Torsional moment.	Decreased..... ...do..... ...do.....	} 5
SULFITE CELLULOSE LYE				
Dolomite.....	50	Bit wear..... Drilling speed. Rock hardness..	Decreased 10 pct..... Increased 20 pct..... Decreased 80 pct.....	} 18
Limestone ⁸	50	Bit wear..... Drilling speed. Rock hardness..	Decreased 10 pct..... Increased 10 to 70 pct. Decreased 30 to 50 pct.	
SULFONAPHTHENIC PETROLEUM ACIDS				
Dolomite.....	1 - 2	Bit wear..... Drilling speed. Rock hardness..	Decreased 10 pct..... Increased 20 pct..... Decreased 80 pct.....	} 18
Limestone ⁸	1 - 2	Bit wear..... Drilling speed. Rock hardness..	Decreased 10 pct..... Increased 10 to 70 pct. Decreased 30 to 50 pct.	
TERGITOL ²⁷				
TERGITOL 7 Amygdaloidal basalt.....	0.1	Drilling costs. Drilling rate..	Reduced..... Increased 20 to 50 pct.	} 4
TERGITOL NPX Amygdaloidal basalt.....	.1	Drilling costs. Drilling rate..	Reduced..... Increased 20 to 50 pct.	

TABLE 2. - Effects of chemical additives on rock and drilling properties, by additive type--Con.

Rock	Concentrations tested, wt pct	Property	Effect ¹	References ²
THORIUM CHLORIDE ⁴				
Argillaceous rocks (shales).....	0.0 - 0.03	Bit wear..... Drilling rate..	Reduced..... Increased 15 to 40 pct.	} 23
Gritstone ⁹	.0 - .03	NP.....	NE.....	
Limestone ⁹	.0 - .03	Bit wear..... Drilling rate..	Reduced..... Increased 9 pct.....	} 23
Sandstone.....	.0 - .03	Bit wear..... Drilling rate..	Decreased..... Increased 15 to 40 pct.	
TOLUENE ⁴				
Calcium fluoride crystals.....	NA	NP.....	NE.....	31
Lithium fluoride crystals ⁹	NA	Bit life.....	Increased.....	13
Magnesium oxide crystals.....	Pure	Drilling rate..	...do.....	15, 32
Quartz.....	Pure	...do.....	Increased 20-fold.....	8
TORQUE TRIM ⁴				
Rhyolite porphyry.....	2.0	NP.....	NE.....	15
WATER ²⁹				
Greenstone ³	Nap	Drilling effectiveness.	Increased to maximum...	11
Lithium fluoride crystals ^{4,9}	Nap	Bit life.....	Increased.....	13
Magnesium oxide crystals ⁴	Nap	Drilling rate..	NE.....	15
Quartz ⁴	Nap	...do.....	Increased 20-fold.....	8
Quartzite ⁴	Nap	NP.....	NE.....	21

NA Not available. Nap Not applicable.

NE No added effects reported. NP No specific property reported.

¹Compared to drilling with water alone.²Numbers refer to items in the list of references preceding the appendixes.³Field test using EX (1.5-in-ID) bit.⁴Laboratory test(s). ⁵Mole per liter.⁶Tests on hematite and taconite. ⁷Test using BX (2.375-in-ID) bit.⁸Field test(s), no bit size given. ⁹Compared to dry drilling, not to water.¹⁰Optimum reported concentration was 0.01 pct. ¹¹Normal concentration (N).¹²Recommended for all low-silica, igneous rocks. ¹³Industrial tests.¹⁴Field test using BX (2.375-in-ID) bit and NX (3.0-in-ID) bit.¹⁵Optimum reported concentration.¹⁶Novo Khazinskii and Arlanskii coal deposits, Arlansk region, field tests.¹⁷Field test using NX (3.0-in-ID) bit.¹⁸New South Wales coal measure, field tests.¹⁹Field test using AX (1.91-in-ID) bit and BX (2.375-in-ID) bit.²⁰Reported that the reactant fluid, calcium chloride, produced the enhanced results.²¹Optimum reported concentration was 0.25 pct.²²Field test using AX (1.91-in-ID) bit.²³Composition of special mud, in percent:

Bentonite clay..... 5.6

Sodium bicarbonate.. .95

Sodium chloride..... 13.4

Tap water..... 80.05

²⁴Methane to decanol.²⁵Naphthenic acid soap, 0.25 to 0.5 wt pct; sodium carbonate, 0.25 wt pct.²⁶Each. ²⁷Field test using AXL (1.185-in-ID) bit.²⁸Optimum reported concentration was 0.1 pct.²⁹Water used as drilling fluid, not just for comparison purposes.

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APPENDIX A.--SUMMARY OF CHEMICAL ADDITIVES USED TO STUDY
VARIOUS PROCESSING METHODS, WITH REFERENCES

TABLE A-1. - Chemical additives tested for various processing methods

Additive	Concentrations tested	Method ¹	References ²
ALUMINUM CRYSTALS			
Aeropromoter 765.....wt pct..	0.25-0.75	C	5
Aeropromoter 765 plus naphthenic acid.....wt pct..	0.2-0.8	C	5
Naphthenic acid.....wt pct..	0.25-0.75	C	5
Oleic acid.....wt pct..	0.25-0.5	C	5
Organosilicon.....wt pct..	0.005	C	3
CALCITE			
Sodium petroleum sulfonates.....	NA	F1	1
CASSITERITE			
Alphaamino valeric acid.....	NA	F1	17
Cupferron.....	NA	F1	17
Laurylamine hydrochloride.....mg/L..	50	F1	17
Sodium laurate.....	NA	F1	17
Sodium oleate.....	NA	F1	17
Sodium pelargonite.....	NA	F1	17
Sodium sulfate.....mg/L..	50	F1	17
CEMENT AND/OR CLINKER			
Acetone.....	Vapor	C	12
Asphaltines.....	NA	C	3
Benzene.....	Vapor	C	12
Calcium sulfate.....	NA	C	3
Carbon blacks.....	NA	C	3
Cod oil.....	NA	C	3
Cyclohexane.....	Vapor	C	12
Diethanolamine.....wt pct..	0.1	C	3
Ethylene glycol.....	Vapor	C	12
Glycol.....	NA	C	3
Kojic oil.....	NA	C	3
n-butylamine.....	Vapor	C	12
Organosilicon.....wt pct..	0.01-0.05	C	3
Propylene glycol.....wt pct..	0.05	C	3
Resins.....	NA	C	3
Triethanolamine.....wt pct..	0.1	C	3, 11, 15
Urea.....	NA	C	3
Water.....	NAP	C	3, 11, 15
Wool grease.....	NA	C	3
CLAY ROCKS			
Sodium chloride.....wt pct..	0.25-0.5	Fr	4
Soluble oils.....wt pct..	0.17	Fr	4
COAL			
Acetone.....	NA	C	2
Anhydrous ethanol.....	NA	C	2
Anhydrous isopropanol.....	NA	C	2
Anhydrous methanoo.....	NA	C	2
Dimethylsulfoxide.....	NA	Fr	18
Distilled water.....	NAP	Fr	18
Ethylamine.....	NA	C	2
Glacial acetic acid.....	NA	C	2
Hexadecane.....	NA	Fr	18
Hexanes.....	NA	Fr	18
Hydrogen peroxide.....	NA	C	2
Liquid ammonia.....	NA	C	2
Methanol.....	NA	C	2
Methyl amine.....	NA	C	2

See notes at end of table.

TABLE A-1. - Chemical additives tested for various processing methods--Con.

Additive	Concentrations tested	Method ¹	References ²
COAL--Continued			
Oleic acid.....	NA	Fr	18
Potassium iodine.....	NA	Fr	18
Saturated aluminum chloride.....mol..	2.49	Fr	18
Saturated calcium chloride.....mol..	2.34	Fr	18
Saturated iron chloride.....mol..	3.42	Fr	18
Saturated sodium chloride.....mol..	5.39	Fr	18
Sodium hydroxide.....	NA	C	2
Sodium silicate.....	NA	Fr	18
Toluene.....	Pure	Fr	18
CORUNDUM			
Sodium chloride.....	NA	Fl	17
Sodium nitrate.....	NA	Fl	17
DOLOMITE			
Calcium hydroxide.....wt pct..	0.05-0.07	Fr	4
Sodium hydroxide.....wt pct..	0.05	Fr	4
Soluble oils.....wt pct..	0.67	Fr	4
GLASS			
Acetone.....	NA	C	3
Benzene.....	NA	C	3
Carbon tetrachloride.....	NA	C	3
Nitromethane.....	NA	C	3
GYPSUM			
Wool grease.....	NA	C	3
HEMATITE (TACONITE)			
Activator AR calcium chloride.....lb/ton..	5-20	C	14
Aluminum chloride.....wt pct..	0.1	Fr	4
Armac D 12.....lb/ton..	0.1-0.7	C	14
Cationic surfactant.....wt pct..	0.2-0.7	Fr	4
Dodecylamine acetate.....mol/L..	10^{-7} - 10^{-3}	C	14
Dodecylammonium chloride.....	NA	Fl	17
Ferric chloride.....wt pct..	0.1	Fr	4
Sodium chloride.....wt pct..	0.1-0.25	Fr	4
Sodium dodecylsulfate.....	NA	Fl	17
Sodium octadecylsulfate.....	NA	Fl	17
Sodium oleate.....	NA	C	14
Sodium silicate.....mg/g..	1.25	C	3
Sulphonic Promoter 801.....lb/ton..	0.3	C	14
XF-4272.....wt pct..	0.02-0.06	C	3
XFS-4272.....lb/ton..	0.5	C	3
LIMESTONE			
Calcium hydroxide.....wt pct..	0.05-0.07	Fr	4
Flotigan P.....wt pct..	0.03	C	3, 16
Sodium carbonate.....wt pct..	0.25	C	6, 10
Sodium hydroxide.....wt pct..	0.05	C	6, 10
Soluble oils.....wt pct..	0.67	Fr	4
MAGNESITE			
Aluminum chloride.....wt pct..	0.1	Fr	4
Cationic surfactant.....wt pct..	0.2-0.7	Fr	4
Ferric chloride.....wt pct..	0.1	Fr	4
Sodium chloride.....wt pct..	0.1-0.25	Fr	4
MARBLE			
Acetone.....	NA	C	3
Benzene.....	NA	C	3
Carbon tetrachloride.....	NA	C	3
Nitromethane.....	NA	C	3

TABLE A-1. - Chemical additives tested for various processing methods--Con.

Additive	Concentrations tested	Method ¹	References ²
QUARTZ			
Acetone.....	Vapor	C	3, 12
Alcohol.....	NA	C	3
Aluminum chloride.....wt pct..	0.02-0.1	C	3, 6
Aluminum nitrate.....eq/L..	10^{-7} - 10^{-1}	Fl	8
Barium nitrate.....eq/L..	10^{-7} - 10^{-1}	Fl	8, 17
Benzene.....	NA	C	3, 12
Carbon tetrachloride.....	NA	C	3
Copper sulfate.....g/L..	1	C	6
Dodecylammonium acetate.....mol/L..	10^{-7} - 10^{-1}	Fl	7, 9, 17
Hydrochloric acid.....mol/L..	0.01	Fl	8
Methyl alcohol.....wt pct..	>10	C	6
MS 66.....wt pct..	1.0	C	6
Nitromethane.....	NA	C	3
Octyl to octadecyl ammonium acetate.....mol/L..	10^{-7} - 10^{-1}	Fl	6
Repelcote.....wt pct..	2.0	C	6
Siliconate D 3032.....wt pct..	1.0	C	6
Sodium chloride.....wt pct..	0.1-0.5	Fl	8, 17
Sodium hydroxide.....mol/L..	10^{-3} - 10^0	Fl	8
Sodium laurate.....eq/L..	10^{-7} - 10^{-1}	Fl	8
Sodium nitrate.....eq/L..	10^{-7} - 10^{-1}	Fl	8
Sodium oleate.....eq/L..	10^{-7} - 10^{-1}	Fl	8
Sodium petroleum sulfonates.....	NA	Fl	1
Water.....	Nap	C	12
Wool grease.....	NA	C	3
QUARTZITE			
Aluminum chloride.....wt pct..	0.02-0.1	Fr	4
Anionic surfactants.....wt pct..	0.4-1.2	Fr	4
Calcium chloride.....wt pct..	0.1-0.2	Fr	4
Flotigan P.....wt pct..	0.03	C	3
Magnesium chloride.....wt pct..	0.1-0.2	Fr	4
Sodium chloride.....wt pct..	0.1-0.5	Fr	4
Soluble oils.....wt pct..	0.5-0.9	Fr	4
RUTILE			
Linoleic acid.....	NA	Fl	17
Linolenic acid.....	NA	Fl	17
Oleic acid.....	NA	Fl	17
Stearic acid.....	NA	Fl	17
SHALE			
Sodium chloride.....wt pct..	0.25-0.5	Fr	4
Soluble oils.....wt pct..	0.17	Fr	4
STEATITE			
Acetone.....	Vapor	C	12
Benzene.....	Vapor	C	12
Water.....	Vapor	C	12
STEEL			
MRS.....	NA	C	13
Ukrinol 14/9.....	NA	C	13
Ukrinol 14/10.....	NA	C	13
URANINITE			
Ferric ion (Fe III).....mol..	10^{-4} - 10^{-2}	Fr	18
Sulfate ion.....mol..	10^{-4} - $10^{-1.82}$	Fr	18
ZIRCON			
Triethanolamine.....wt pct..	0.2	C	3

NA Not available. Nap Not applicable.

¹C = comminution or grinding; Fl = flotation; Fr = fragmentation.²Numbers refer to items in the list of references following the table.

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APPENDIX B.--SUMMARY OF CHEMICAL ADDITIVES USED IN SURFACE
EFFECTS STUDIES, WITH REFERENCES

TABLE B-1. - Chemical additives tested in measuring various surface effects

Additive	Concentrations tested	Effects ¹	References ²
ALUMINUM CRYSTALS			
Dry air.....	Nap	F	3
Hexadecane.....	NA	F	3
Mercury.....	NA	F	3
ALUMINUM OXIDE			
n-alcohols.....	NA	Z	17-18
Sodium hydroxide.....	NA	Z	17-18
CALCITE			
Benzene.....	NA	S	19
Nitric acid.....	NA	Z	18
Sodium hydroxide.....	NA	Z	18
Water.....	Nap	S	19
CALCIUM FLUORIDE			
Aluminum chloride.....wt pct..	0.0-0.2	R	5
Calcium chloride.....	NA	R	27
DMF.....wt pct..	0-100	R	5, 27
DMSO.....wt pct..	0-100	R	5, 27
DMF in DMSO.....wt pct..	0-50	R	5, 27
n-heptane to n-hexadecane.....wt pct..	Varied	R	5
Silver chloride.....	NA	R	27
Silver nitrate.....	NA	R	27
Sodium chloride.....	NA	R	27
Toluene ³	Pure	R	5, 27
CHRYSOTILE			
Potassium chloride.....N..	10 ⁻⁵	Z	20
Sodium carbonate plus sodium phosphate mol/L..	10 ⁻²	Z	20
Sodium silicate.....	NA	Z	20
FOSTERITE			
Water.....	Nap	Z	15
GERMANIA			
Fluorobenzene.....	NA	A	23
GLASS			
Aluminum nitrate.....mol/L..	10 ⁻⁸ -10 ⁻²	Z	1
Calcium chloride.....mol/L..	10 ⁻⁴ -10 ⁻²	Z	12
Calcium nitrate.....mol/L..	10 ⁻⁸ -10 ⁻²	Z	1
Crystal violet.....mol/L..	10 ⁻⁸ -10 ⁻²	Z	1
Hydrochloric acid.....wt pct..	Varied	Z	12
Lanthium chloride.....mol/L..	10 ⁻⁴ -10 ⁻²	Z	12
n-alcohols (methanol to dodecyl).....	NA	F, Z	16, 18, 29
Potassium chloride.....mol/L..	10 ⁻⁸ -10 ⁻²	Z	1
Sodium chloride.....mol/L..	10 ⁻⁴ -10 ⁻²	Z	12
Sodium dodecyl sulfate.....	NA	S	22
Sodium tetradecyl sulfate.....	NA	S	22
Synovial fluid.....	NA	S	22
Tetradecyldimethyl ammonium bomide.....	NA	S	22
Thorium nitrate.....mol/L..	10 ⁻⁸ -10 ⁻²	Z	1
Toluene.....	NA	Z	18

See notes at end of table.

TABLE B-1. - Chemical additives tested in measuring various surface effects--Con.

Additive	Concentrations tested	Effects ¹	References ²
GRANITE			
Aluminum chloride.....mol/L..	3×10^{-6} - 1×10^{-4}	Z	6
DTAB.....mol..	10^{-3}	Z	18
n-alcohols.....	NA	Z	18
Oleylammonium acetate.....	NA	Z	6
Toluene.....	NA	Z	18
LIMESTONE			
Aniline.....	NA	R	11
Benzaldehyde.....	NA	R	11
Benzene.....	NA	R	11
Ethyl alcohol.....	NA	R	11
Ethylene glycol.....	NA	R	11
Glycerine.....	NA	R	11
n-butyl alcohol.....	NA	R	11
Nitrobenzene.....	NA	R	11
1,3-dibromopropane.....	NA	R	11
Toluene.....	NA	R	11
LITHIUM FLUORIDE			
Aluminum chloride.....wt pct..	0.1	R	5
Caprylic to stearic acids.....N..	10^{-6} - 10^{-2}	R	26
DMF.....wt pct..	0-100	R; Z	5; 17
DMSO.....wt pct..	0-100	R	5
DMF in DMSO.....wt pct..	0-50	R	5
Hexadecane.....	NA	F	4
Hexadecane with organic acids.....	NA	F	4
Oleic acid.....	NA	F	4
Toluene.....	NA	R; Z	5; 17
Water.....	NAP	R; Z	5; 17
MAGNESIUM OXIDE			
Aluminum chloride.....wt pct..	0.1	R	5
DMF.....wt pct..	0-100	F; R; Z	16; 5, 28; 18
DMSO.....wt pct..	0-100	F; R; Z	16; 5, 28; 18
DMF in DMSO.....wt pct..	0-50	F; R	16; 5, 28
n-heptane to n-hexadecane.....wt pct..	Varied	F; R	16; 5
Sodium chloride.....N..	10^{-2}	F; Z	16; 17
Toluene.....	NA	Z	18
Water.....	NAP	F	16
QUARTZ			
Aluminum chloride.....wt pct..	0.02-0.1	F	25
Ammonium acetate.....mol/L..	10^{-7} - 10^{-1}	Z	8
Calcium chloride.....mol..	10^{-4} - 10^{-2}	Z	12
Cetyltrimethyl ammonium bromide.....	NA	S	30
Decylammonium acetate.....mol/L..	10^{-7} - 10^{-1}	Z	8
Dodecylammonium acetate.....mol/L..	10^{-7} - 10^{-1}	Z	7-8
Dodecylammonium acetate plus sodium carbonates.....mol/L..	10^{-4} - 6×10^{-5} 1.6×10^{-4} - 10^{-3}	Z	8
DTAB.....	NA	Z	18
Hexadecylammonium acetate.....mol/L..	10^{-7} - 10^{-1}	Z	8
Hydrochloric acid.....mol/L..	0.1	Z	12
Lanthium chloride.....mol..	10^{-4} - 10^{-2}	Z	12

TABLE B-1. - Chemical additives tested in measuring various surface effects--Con.

Additive	Concentrations tested	Effects ¹	References ²
QUARTZ--Continued			
n-alcohols.....	NA	Z	18
Octylammonium acetate.....mol/L..	10 ⁻⁷ -10 ⁻¹	F; Z	25; 8
Potassium chloride.....	NA	Z	18
Potassium iodide in isopropyl alcohol.....	NA	Z	18
Sodium chloride.....wt pct..	0.1-0.5	S; Z	30; 12
Do.....mol/L..	10 ⁻⁴ -10 ⁻³		
Sodium dodecyl sulfate.....	NA	S	30
Tetradecylammonium acetate.....mol/L..	10 ⁻⁷ -10 ⁻¹	Z	8
Thorium nitrate.....	NA	Z	18
SILICA			
Acetone.....	NA	A	9
Benzene.....	NA	A	9
Calcium chloride.....mol..	10 ⁻⁴ -10 ⁻²	Z	12
CTAB.....	NA	A	2
Diethyl ether.....	NA	A	9
DTAB.....	NA	A	2
Hexane.....	NA	A	9
Hydrochloric acid.....wt pct..	Varied	Z	12
Lanthium chloride.....mol..	10 ⁻⁴ -10 ⁻²	Z	12
Methanol.....	NA	A	9
Pyridene.....	NA	A	9
Sodium chloride.....mol..	10 ⁻⁴ -10 ⁻²	Z	12
Triethylamine.....	NA	A	9
Water.....	NAp	A	9
STEEL			
Benzene.....	NA	R	13
Carbon tetrachloride.....	NA	S	24
Molybdenum sulfate.....	NA	F	10
Oleic acid.....	NA	R	13
Stearic acid.....wt pct..	0.1	A	14
Tungsten sulfate.....	NA	F	10
TIN			
Allyl alcohol.....	NA	A	14
Dodecyl alcohol.....	NA	A	14
Lauryl chloride.....	NA	A	14
Methyl laurate.....	NA	A	14
n-propyl alcohol.....	NA	A	14
Octylamine.....	NA	A	14
Oleic acid.....	NA	A	21
Paraffin.....wt pct..	0.2	A	21
Saturated fatty alcohols.....	NA	A	14
ZINC CRYSTALS			
Oleic acid.....wt pct..	0.1	A	21
Paraffin.....wt pct..	0.2	A	21

NA Not available. NAp Not applicable.

¹A = adsorption; F = friction and wear; R = Rebinder effect; S = surface effects; Z = zeta potential.²Numbers refer to items in the list of references following the table.³<0.02 pct water.

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APPENDIX C.--SUMMARY OF CHEMICAL ADDITIVES USED TO STUDY
VARIOUS MECHANICAL PROPERTIES, WITH REFERENCES

TABLE C-1. - Chemical additives tested for measuring various mechanical properties

Additive	Concentrations tested	Properties ¹	References ²
ALUMINA			
n-alcohols.....	NA	F	24
Toluene.....	NA	F	24
Water.....	Nap	F	24
ALUMINUM CRYSTALS			
Distilled water.....	Nap	F	4
Dry air.....	Nap	F	4
Methanol.....	NA	F	4
Organic liquids.....wt pct..	0-100	H	15
Sea water.....	Nap	F	4
Stearic acid.....mol/L..	0.0-2.1	M	9
ALUMINUM OXIDE			
Toluene.....	NA	H	23
CADMIUM CRYSTALS			
Oleic acid.....mol/L..	0.1-2.1	M	9
CALCITE			
Butyl alcohol ³	Pure	F	24
Colophonium.....	NA	H	8
Fatty alcohols.....	NA	S	13
n-butyric acid.....	NA	H	8
n-propyl alcohol.....	NA	H	8
Oleic acid in Toluol.....	NA	H	8
Oleic acid in vaseline oil.....	NA	H	8
Phenol in benzene.....	NA	H	7
Polar liquid.....	Pure	H	7-8
CALCIUM FLUORIDE			
Air.....	Nap	H	17
DMF.....wt pct..	0-100	F; H; M	21, 24; 23; 22
DMSO.....wt pct..	0-100	H; M	23; 22
DMF in DMSO.....wt pct..	0-50	H	23
Isooctane.....	NA	H	23
n-heptane to n-hexadecane.....	NA	F	21
Nitrogen.....	Nap	H	17
Oxygen.....	Nap	H	17
Toluene.....	NA	F; H	21; 23
Water.....	Nap	H	23
CEMENT-CLINKER			
Naphthalene sulphonic acid.....	NA	M	12
COPPER			
Toluene.....	NA	H	23
GERMANIA			
Toluene.....	NA	H	23
GLASS			
Acetone.....	NA	F; H	24; 23
Aluminum chloride.....N..	10 ⁻³ -10 ⁻²	S	20
Dodecylammonium chloride.....N..	10 ⁻⁵ -10 ⁻²	S	20
Fatty alcohols.....	NA	S	13
Iso-amyl alcohol.....wt pct..	2.5	H	23
n-alcohols.....wt pct..	Varied	F; H	24; 23
n-alkanes.....	NA	H	23
Potassium chloride.....	NA	H	23
Sodium carbonate.....wt pct..	10 ⁻⁵	S	20
Sodium dioctyl sulfonsuccinate.....wt pct..	0.5	H; S	23; 13
Stearamidomethyl pyridinium chloride.....	NA	S	20

See notes at end of table.

TABLE C-1. - Chemical additives tested for measuring various mechanical properties--Con.

Additive	Concentrations tested	Properties ¹	References ²
GLASS--Continued			
Thorium nitrate.....	NA	H	23
Toluene.....	NA	F; H	24; 23
Velan.....wt pct..	0.5	H	23
Water.....	NAP	F; H; S	24; 23; 20
GOLD			
Oleic acid.....	NA	M	12
GRANITE			
DTAB.....mol/L..	10 ⁻⁴	F; H	24, 11; 23
n-alcohols.....	NA	F; H	24; 23
Toluene.....	NA	F	24
Water.....	NAP	F	24
GRAPHITE ORES			
Acetic acid.....	NA	H	3
LIMESTONE			
α -hydroxyladipaldehyde.....	NA	H	14
α -nitro β -naphthol.....	NA	H	14
Analine.....	NA	H	6
Armac CD-50.....	NA	H	14
Benzaldehyde.....	NA	H	6
Benzene.....	NA	H	6
Benzyl dimethylamine.....	NA	H	14
Calcium chloride.....	NA	H	14
Detergent RAS.....wt pct..	0.25	M	18
DMS.....	NA	H	14
Ethyl alcohol.....	NA	H	6
Ethylene diamine.....	NA	H	14
Ethylene glycol.....	NA	H	6
Glycerine.....	NA	H	6
Mine water.....	NAP	M	18
MRYJ 52.....	NA	H	14
n-butyl alcohol.....	NA	H	6
n-hexadecane.....	NA	S	1
Nitrobenzene.....	NA	H	6
Oleic acid.....	NA	S	1
Nonpolar kerosine.....	Pure	M	18
l-leucine.....	NA	H	14
1,3-dibromopropane.....	NA	H	6
Saturated calcium chloride.....	NA	S	1
Sodium adipate.....	NA	H	14
Sodium azelate.....	NA	H	14
Sodium carbonate.....wt pct..	0.25	M	18
Sodium citrate.....	NA	H	14
Sodium glutarate.....	NA	H	14
Sodium mercaptosuccinate.....	NA	H	14
Sodium oleate.....	NA	H	14
Sodium oxalate.....	NA	H	14
Sodium piccrate.....	NA	H	14
Sodium salts of dicarboxylic acid.....	NA	H	14
Sodium thioxanates.....	NA	H	14
Stearic acid.....wt pct..	0.1	M	18
Toluene.....	NA	H	6
WR 2472.....	NA	H	14
LITHIUM FLUORIDE			
DMF.....wt pct..	0-100	F	21
Heptane.....	NA	F	21
Hexadecane.....	NA	F	21

TABLE C-1. - Chemical additives tested for measuring various mechanical properties--Con.

Additive	Concentrations tested	Properties ¹	References ²
LITHIUM FLUORIDE--Continued			
Myristic acid.....	NA	H	23
Toluene ⁴	Pure	F; H	21; 23
Water.....	NAP	F	21
MAGNESIUM OXIDE			
DMF.....wt pct..	0-100	F; H; M	21, 24; 23; 22
DMSO.....wt pct..	0-100	H; M	23; 22
DMF in DMSO.....wt pct..	0-50	H	23
n-alcohols.....	NA	H	23
n-heptane to n-hexadecane.....	NA	F	21
Toluene ⁴	Pure	F; H	21; 23
Water.....	NAP	H	23
MARBLE			
Detergent RAS.....wt pct..	0.25	M	18
Mine water.....	NAP	M	18
Nonpolar kerosine.....	Pure	M	18
Sodium carbonate.....wt pct..	0.25	M	18
Stearic acid.....wt pct..	0.1	M	18
MICA			
Fatty alcohols.....	NA	S	13
NICKEL (Ni-Al)			
Toluene.....	NA	H	23
POTASSIUM BROMIDE			
Toluene.....	NA	H	23
QUARTZ			
Aluminum nitrate.....mol/L..	10 ⁻⁷ -10 ⁻²	F; H	24; 23
Ammonia.....	NA	M	16
DTAB.....mol/L..	2.5×10 ⁻⁵ -10 ⁻³	F	24
Phosphoric acid.....	NA	M	16
Sulfuric acid.....	NA	M	16
QUARTZITE			
Aluminum chloride.....wt pct..	0.02-0.1	S	19
Naphthenic oil with sodium carbonate.....wt pct..	0.2-5		
	0.25	S	19
Sodium chloride.....wt pct..	0.1-0.5	S	19
SANDSTONE			
Aluminum chloride.....wt pct..	0.02-0.1	S	20
Distilled water.....	NAP	S	1, 20
Dodecylammonium chloride.....N..	10 ⁻⁵ -10 ⁻²	S	20
DTAB.....	NA	F	10
n-hexadecane.....	NA	S	1
Oleic acid.....	NA	S	1
Oleylamine.....	NA	S	1
Sodium azelate.....wt pct..	2.0	H	14
Sodium carbonate.....wt pct..	0.25	S	20
Sodium dodecyl sulfate.....	NA	F	10
Triton x-100.....	NA	F	10
SILICA			
Acetone.....	Vapor	F	5
Benzene.....	Vapor	F	5
Ethyl acetate.....	Vapor	F	5
Ethyl alcohol.....	Vapor	F	5
n-butyl alcohol.....	Vapor	F	5
n-propyl alcohol.....	Vapor	F	5
Water.....	NAP	F	5

See notes at end of table.

TABLE C-1. - Chemical additives tested for measuring various mechanical properties--Con.

Additive	Concentrations tested	Properties ¹	References ²
STEEL			
Acetic anhydride.....	NA	H	15
Acetone.....	NA	M	2
Acetone with dioctyl sebecate.....	NA	M	2
Alcohols.....	NA	M	2
Butyl lithium.....	NA	H	15
Caprylic acid.....	NA	H	15
Carbolic acid.....	NA	H	15
Carbon tetrachloride.....	NA	H	15
Chloroform.....	NA	H	15
dibutyl mercury.....	NA	H	15
diethyl mercury.....	NA	H	15
Dioxane.....	NA	H	15
Hexane.....	NA	M	2
Iso-octane.....	NA	M	2
Light mineral oil.....	NA	H	15
Methyl chloride.....	NA	H	15
Mineral oils.....	NA	M	2
Myristic acid.....	NA	H	15
Oil 12 with stearic acid.....wt pct..	0.1	H	15
Palmitic acid.....	NA	H	15
Parafinic acids.....	NA	M	2
Propionic acid.....	NA	H	15
Propyl chloride.....	NA	H	15
Tetra-n-butyl tin.....	NA	H	15
TIN			
Acetone.....	NA	M	2
Acetone with dioctyl silicate.....	NA	M	2
Alcohols.....	NA	M	2
Allyl alcohol.....	NA	S	13
Caprylic acid.....	NA	M	9
Dodecyl alcohol.....	NA	S	13
Hexane.....	NA	M	2
Iso-octane.....	NA	M	2
Lauryl chloride.....	NA	S	13
Methyl laurate.....	NA	S	13
Mineral oils.....	NA	M	2
n-propyl alcohol.....	NA	S	13
Octylamine.....	NA	S	13
Oleic acid.....	NA	M	9
Paraffinic acids.....	NA	M	2
Propionic acid.....	NA	M	9
Saturated fatty alcohols.....	NA	S	13
Sodium dioctyl sulfosuccinate.....	NA	S	13
Stearic acid.....	NA	M	9
Toluene.....	NA	H	23
TITANIUM CARBIDE			
Toluene.....	NA	H	23
ZINC CRYSTALS			
Oleic acid.....wt pct..	0.1	M	9

NA Not available. NAp Not applicable.

¹F = fracture and crack propagation; H = hardness; M = mechanical properties; S = strength of materials.²Numbers refer to items in the list of references following the table.³10 pct water.⁴<0.02 pct water.

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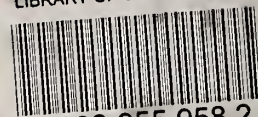
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